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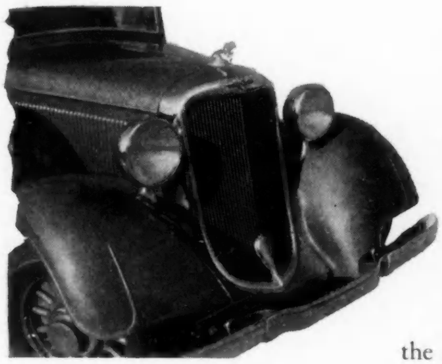
CONTENTS

STRIKING ENGINEERING PROGRESS REVEALED IN 1933 CARS

By AUSTIN M. WOLF



DODGE FRONT-END

SUPERIOR design and enhanced beauty characterize the new cars. This alone is an accomplishment, but, when coupled with the new low prices, it makes the result noteworthy and is indicative of the close cooperation between the engineering and the production departments. New performance characteristics—the ability of accomplishing high mileage without the need of servicing, and endurance under long-sustained high speed—have been embodied in the low-priced cars. The "small" car is being reintroduced, as exemplified by the Willys and Continental fours.

Prominent features in the new models are simplification of control in the passenger-cars and greater ease of control in commercial vehicles. Metallurgical accomplishments are the Waukesha cylinder alloy-iron and Proferall. The White 12-cylinder horizontal engine and the Duesenberg supercharged engine are noteworthy. Other engine details of note are hydraulic valve-lifters, the center-of-gravity adjustment of connecting-rods, the automatic choke and fast idle, the automatic hot-spot control and the accelerator pedal-starter control. Chassis accomplishments of prominence are: the pendulum clutch-control cushion valve; the shifting of a helical gear on a helical spline; spindle bearings in the transmission, universal-joints and steering-gear; the reintroduction of the worm-drive axle; smaller wheels; and power steering in commercial vehicles. Prominent body features include fender valances, concave rear body-panels, the No-Draft ventilating system and a rain-proof cowl ventilator.

Changes in Powerplants

The outstanding powerplant of the year is the 12-cylinder horizontal White engine for bus work shown in Fig. 1, which makes possible a clear floor space for the carrying of passengers and also contributes to a low center of gravity. With the radiator at the front, an accessories unit comprising the fan, water-pump, air compressor, generator and steering servo-pump is driven by a shaft extending from the front end of the engine. The unit is shown in Fig. 2.

Among the passenger-car engines the four-cylinder engine has been dropped by Plymouth but reappears in the new Willys and Continental fours. There has been a slight increase in compression ratio (See Table 1), contributing to greater output, as does improved carburetion and the maintenance of more uniform mixture temperatures. Entirely new engine designs are to be found in the Plymouth six, the Pontiac straight-eight and the Willys Models 77 and 99. The stroke has been increased ¼ in. in the Chevrolet, bringing the displacement to 206.8 cu. in. The Oldsmobile-six displacement has been increased from 213.3 to 221.4 cu. in. It is significant that Pontiac has dropped the V-eight in favor of the straight eight. The new engines in many cases show speed possibilities approaching 4000 r.p.m.

Table 1 gives compression ratios based on cylinder dimensions and number. Volumetric efficiency varies in different engines depending on manifolding, valve timing, valve diameter and lift, and so on. It is difficult to compare engines on the basis of compression ratios alone without volumetric efficiency figures. Comparisons on the basis of brake mean effective pressure would be more suitable.

There has been a demand for a small heavy-duty four-cylinder engine for small trucks and door-to-door delivery wagons, this same engine being applicable also to the industrial, marine and agricultural fields.

The different engine manufacturers have developed a very complete series of engines, allowing the selection of different bores with the same stroke and without change in mounting and general dimensions. These are sometimes held in different models. Use of the eight-cylinder engine in trucks is increasing. The automotive Diesel is being investigated in the truck field, but its application to passenger-cars is most remote.

Alloy Iron and Aluminum for Blocks and Heads

A very noteworthy achievement of the year is the special cylinder alloy-iron developed by the Waukesha Motor Co. It has a low rate of growth, a tensile strength of 60,000 lb. per sq. in. and a Brinell hardness between 280 and 300. It also shows high resistance to valve sinking, and engines built of this material have been operated from 30,000 to 50,000 miles without regrinding of the valves. The Hercules Motors Corp. is using

BUICK CONCAVE PANEL

[Major trends in automobile design, mechanical improvements and changes in practice by prominent maufacturers are reviewed in this article, which continues the series of annual reviews of engineering progress initiated in the S.A.E. JOURNAL five years ago. The author is a Member of the Society and a consulting automotive engineer, New York City.]

TABLE 1—DATA OF ENGINES IN CARS OF 1933

Car	Model	No. of Cylinders	Bore and Stroke, In.	Displacement, Cu. In.	Compression Ratio[a]	Maximum Horsepower	R.P.M. at Maximum Horsepower	Intake Valve Opens, Deg.	Intake Valve Closes, Deg.	Exhaust Valve Opens, Deg.	Exhaust Valve Closes, Deg.	Piston Make	Piston Material	Piston Type	Cylinder Arrangement
Buick	50	8	2 15/16x4 1/4	230.4	5.25 4.84	86 83	3200 3200	4½ BTC	54 ABC	58 BBC	30 ATC	Own	Cast Iron	Tin Plated	In Line
Buick	60	8	3 1/16x4 5/8	272.6	5.25 4.84	97 91	3200 3200	4½ BTC	54 ABC	58 BBC	30 ATC	Own	Cast Iron	Tin Plated	In Line
Buick	80, 90	8	3 5/16x5	344.8	4.8 4.4	113 105	3200 3200	4½ BTC	54 ABC	58 BBC	30 ATC	Own	Cast Iron	Tin Plated	In Line
Cadillac 8 and La Salle	355C, 345C	8	3 3/8x4 15/16	353	5.4 5.7	115	3000	6 BTC	42 ABC	38 BBC	2 ATC	Own	Molybdenum Cast Iron	Tin Plated	V-90 Deg.
Cadillac 12	370C	12	3 1/8x4	368	5.6 5.4, 4.9	135	3400	TDC	44 ABC	39 BBC	5 ATC	Own	Molybdenum Cast Iron	Tin Plated	V-45 Deg.
Cadillac 16	452C	16	3 x4	452	5.7 5.4, 4.9	165	3400	TDC	44 ABC	39 BBC	5 ATC	Own	Molybdenum Cast Iron	Tin Plated	V-45 Deg.
Chrysler 6	CO	6	3½x4½	224	5.35 6.2	83 89	3400 3400	6 ATC	46 ABC	42 BBC	8 ATC	Lynite	Aluminum-Alloy	Lo-Ex	In Line
Chrysler Royal 8	CT	8	3¼x4 1/8	273.8	5.2 6.2	90 98	3400 3400	6 ATC	46 ABC	42 BBC	8 ATC	Lynite	Aluminum-Alloy	Lo-Ex	In Line
Chrysler Imperial 8	CQ	8	3¼x4½	298.6	6.2 5.2	108 100	3400 3400	6 ATC	46 ABC	42 BBC	8 ATC	Lynite	Aluminum-Alloy	Lo-Ex	In Line
Chrysler Imperial Custom 8	CL	8	3½x5	384.8	5.8 5.2	135 125	3200 3200	6 ATC	46 ABC	42 BBC	8 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Continental Beacon	C-400	4	3 3/8x4	143.12	5.05	40	2700	TDC	40 ABC	35 BBC	5 ATC	Own	Cast Iron	....	In Line
Continental Flyer	C-600	6	3 x4	169.64	5.21	65	3500	TDC	46 ABC	50 BBC	6 ATC	Own	Cast Iron	....	In Line
De Soto	SD	6	3¼x4 3/8	217.7	5.35 6.2	79 86	3400 3400	6 ATC	46 ABC	42 BBC	8 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Dodge 6	DP	6	3 1/8x4 3/8	201.3	5.5 6.5	75 81	3600 3600	6 ATC	46 ABC	42 BBC	8 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Dodge 8	DO	8	3¼x4¼	282.1	6.2 5.2	100 92	....	6 ATC	46 ABC	42 BBC	8 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Graham	Standard 6	6	3¼x4½	224	6.5	85	3400	TDC	40 ABC	40 BBC	10 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Graham	Standard 8	8	3 1/8x4	245.4	6.5	95	3400	TDC	40 ABC	40 BBC	10 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Hudson	Super-Six	6	2 15/16x4¾	193	6.2	70	3200	30 BTC	80 ABC	60 BBC	25 ATC	Lynite	Aluminum-Alloy	Lo-Ex	In Line
Hudson	Terraplane 8	8	2 15/16x4½	245	5.8	94	3200	30 BTC	80 ABC	60 BBC	25 ATC	Lynite	Aluminum-Alloy	Lo-Ex	In Line
Oldsmobile 6	F 33	6	3 3/8x4 1/8	221.4	5.3 6.0	80	3200	TDC	50 ABC	40 BBC	10 ATC	Own	Cast Iron	Tin Plated	In Line
Oldsmobile 8	L 33	8	3x4¼	240.3	5.5 6.5	90	3350	TDC	42 ABC	40 BBC	10 ATC	Own	Cast Iron	Tin Plated	In Line
Pierce-Arrow	836	8	3½x4¾	366	5.5	135	3400	5 ATC	45 ABC	40 BBC	12 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Pierce-Arrow	1236	12	3 3/8x4	429	6.0	160	3400	4 BTC	52 ABC	40 BBC	16 ATC	Bohn	Aluminum-Alloy	Invar-Strut	V-80 Deg
Plymouth	PC	6	3 1/8x4 1/8	189.8	5.5 6.5	70 76	3600 3600	6 ATC	46 ABC	42 BBC	8 ATC	Lynite	Aluminum-Alloy	Lo-Ex	In Line
Pontiac		8	3 3/16x3½	223.4	5.7	77	3600	5 BTC	39 ABC	45 BBC	5 ATC	Own	Cast Iron	Tin Plated	In Line
Studebaker 6	56	6	3¼x4 5/8	230	5.5 6.0	85	3200-3600	5 ATC	53 ABC	38 BBC	10 ATC	Own	Cast Iron	Tin Plated	In Line
Studebaker Commander	73	8	3 1/16x4	236	5.5 6.0	100	3800	15 BTC	43 ABC	48 BBC	10 ATC	Own	Cast Iron	Tin Plated	In Line
Studebaker President	82	8	3 1/16x4¼	250.4	5.5 6.0	110	3600-2800	15 BTC	43 ABC	48 BBC	10 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Studebaker President	92	8	3½x4 3/8	337	5.5 6.0	132	3400-3600	5 ATC	45 ABC	40 BBC	12 ATC	Bohn	Aluminum-Alloy	Invar-Strut	In Line
Willys 6	99	6	3 5/16x4 1/8	213.3	5.26	80	3400	TDC	38 ABC	34 BBC	4 ATC	Own	Cast Iron	....	In Line
Willys 4	77	4	3 1/8x4 3/8	134	5.1	45	3200	TDC	45 ABC	40 BBC	5 ATC	Own	Cast Iron	....	In Line

[a] Lower figure signifies optional.

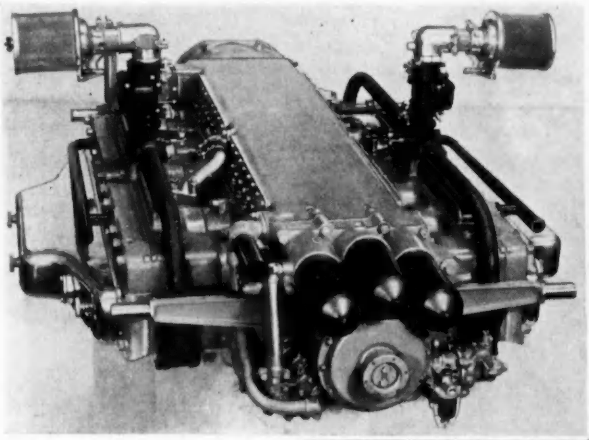


Fig. 1—White Horizontal 12-Cylinder Engine

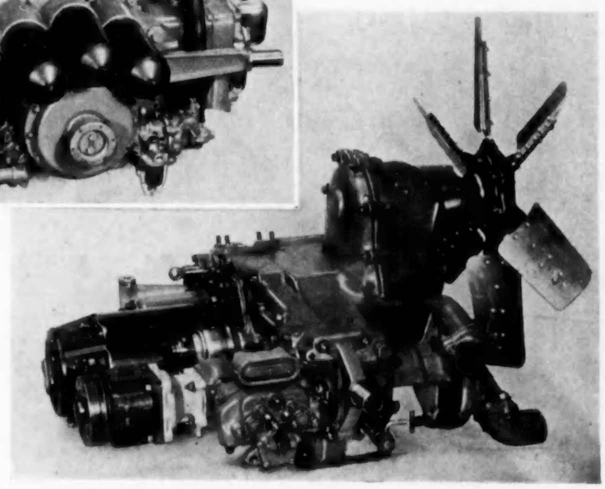


Fig. 2—White Engine-Accessories Unit

three types of cylinder material; standard cylinder iron, nickel-chromium and electric-furnace molybdenum iron.

The White 12-cylinder engine has an aluminum-alloy head to help eliminate any tendency to detonate. The Aluminum Co. of America claims that, without any other changes in the engine, an aluminum head, through an increase in compression ratio, will contribute to an increase of 10 to 15 per cent in power.

Graham now uses an aluminum head, while the Hudson Super-Six has a composite type in which the combustion-chamber side is made as a permanent-mold casting to assure a denser metal and more uniform combustion chambers. The upper half of the head is an ordinary gray-iron casting.

Improvements in Valves and Valve Mechanism

The exhaust-valve insert has taken a strong hold, being used in the entire Chrysler group, the Willys four and six, Franklin, General Motors truck, Hercules in some models, White and Mack. The Chrysler group uses a tungsten-chromium-nickel alloy, resulting in a mileage in excess of 25,000 without the need of regrinding. Franklin is using Ni-Resist exhaust-valve seats, while Willys utilizes high-speed steel. In the G.M.T.-400 engine, stellite-faced valve-inserts are screwed into the nickel-iron cylinder head. The exhaust-valve heads are tulip-shaped for greater heat conductivity and to thwart distortion. The White 12 retains the characteristic screwed-in type, this L-head engine having its valves on the under side for accessibility.

Pierce-Arrow has introduced the automatic hydraulic valve-lifter shown in Fig. 3. Within each tappet is located a well-fitted plunger. Oil under pressure from the lubricating system presses the plunger against the valve, making zero clearance. A ball check-valve in the base of the plunger prevents the oil escaping when the valve load is impressed upon it. Some oil escapes at each lift stroke but, when the valve again seats and the load is momentarily absent, engine-oil pressure, aided by a very light spring under the plunger, causes a refilling of the lifter. The design eliminates noise and assures correct valve-seating and prevention of valve deterioration.

With higher compression ratios and consequent lowering of the roof of the combustion chamber down toward the piston and the block, the Pierce-Arrow company, on its 12-cylinder engine, found that a restriction of the inlet charge developed between the roof of the combustion chamber and the top deck of the cylinder block between the valves and the bore. To straighten the path of the inlet charge entering the cylinder and to provide a greater throat area, the top deck of the cylinder block is chamfered or cut down from the valves to the bore. A considerable improvement in torque and power is claimed for this construction.

Larger Port Opening and Water Space

In both the G.M.T.-400 engine and the Pierce-Arrow the port opening has been increased and given a venturi shape for increased mixture flow into the cylinder. Adequate water space around the exhaust-valve seats is essential for long valve life and good seal. It plays an important part in the new Pontiac eight, which was designed without the customary restriction on over-all length. Hercules engines have ample cooling provided at this point, as shown in Fig. 4. At the same time, a clean casting is obtained by the avoidance of delicate coring.

Dodge and Plymouth engines aim at prevention of oil being sucked into the combustion chamber on the intake stroke by having a wide circular groove cut in the lower end of the valve-stem to break the oil seal in the valve-guide. The groove coincides with a chamfer in the lower end of the guide as the valve rises. Chrysler grades the valve-springs into five classifications according to tension, and fits like springs to an engine to assure uniform valve functioning.

Width of the valve seat has been reduced in the Chevrolet and the side thrust on the valve stem is lessened by better rocker-arm geometry and reduction of the radius on the end of the rocker-arm. In view of high speeds, the valve tappets have been lightened and heavier valve springs are used. Provision is made for a constant supply of oil in the rocker shaft at any speed and also when starting. In the Willys four and six, conically ground tappet faces are used for quiet operation. The Packard and Hupp eights continue use of the rocker-arm-type lifters.

It has been common practice to make the exhaust valve $\frac{1}{8}$ in. smaller in diameter than the inlet valve. The importance of the relative cylinder and atmospheric pressures had not been fully realized until the Waukesha company, in its Full Power line, which is characterized by the intake valve in the head and the exhaust valve at the side, showed that in a $4\frac{3}{8} \times 5\frac{1}{8}$-in. cylinder with a $2\frac{1}{8}$-in. inlet and $1\frac{7}{8}$-in. exhaust valve it was still possible to obtain 1 hp. from 3.7-cu.-in. displacement of mixture.

There has been a pronounced tendency toward higher brake mean effective pressures in the upper speed range of

* Lower figure signifies optional.

heavy-duty engines, and Waukesha went to the F-head to avoid the serious drop in volumetric efficiency due to inadequate breathing capacity in L-head engines. An inlet valve over the piston can be made as large as desired and a high lift obtained by properly proportioning the rocker arm. Waukesha has obtained a volumetric efficiency of 88 per cent at 1800 r.p.m. and 83 per cent at 2800 r.p.m. Although the commercial product has run about 105 lb. per sq. in. b.m.e.p., some tests show as high as 115 lb.

Any one of the Full Power engines will show a fuel economy of 0.52 lb. per b-hp.-hr. on the test block and 129 ton-miles per gal. in truck-fleet operation when fitted with standard carbureters and with no particular provision for high economy. Another interesting performance fact is that maximum power on the test block can be obtained at 0.58 lb. per h-hp.-hr., a difference of only 0.06 lb. per b-hp.-hr. between maximum power and best economy.

New Materials for Camshafts and Valve Gears

Proferall, an electric-furnace cast-iron alloy containing nickel, chromium and molybdenum, as developed by the Campbell, Wyant & Cannon Foundry Co., is used for camshafts in the Terraplane. It is made in a combination mold of metal and sand, with chilling surfaces for the nose of the cams and eccentric surfaces, and gives a tensile strength of 50,000 lb. per sq. in., although two other grades reach 60,000 and 70,000 lb. The alloy shows little grain growth, and allowances provided in bearing fits for lubrication are not absorbed by expansion. There is a considerable saving over the forged shaft in the way of dies, heat-treating and plating equipment and machining operations. Considerable talk has been heard about cast-iron crankshafts, and Proferall is being experimented with as well as the Waukesha alloy.

Celeron, a spoke type of phenolic material, has been developed for camshaft drive and is claimed to possess over the solid-web gears of that type such characteristics as quietness, low operating temperature and reduced wear, and to compare favorably with the solid-web type for lateral rigidity. It is interesting to note that the Plymouth, Continental and Willys in the low-priced field have a silent-chain camshaft drive. Chevrolet has a center camshaft bearing consisting of a steel-backed babbitt-lined bushing.

Pistons and Piston-Rings

In a new type Lynite T-slot piston used in the White, Reo, Hudson, Essex, Plymouth and Chrysler a horizontal slot is located in the bottom ring-groove, and from the center thereof the slot extends downward at a slight angle to the piston axis toward but not through the bottom of the skirt, eliminating the possibility of collapse and providing a continuous band at the bottom which can be fitted quite closely to the bore. In the cars mentioned, Lo-Ex No.-132 alloy, is used. The pistons are cam-ground to elliptical shape so as to be circular at normal temperatures.

In the G.M.T.-400 and the Waukesha Full Power engines aluminum-alloy pistons are used, together with full-floating piston-pins held in place endwise by aluminum keepers. In the Plymouth, Dodge and Willys engines the pins are held by spring snap-ring retainers. The Dodge engine has aluminum-alloy pistons with invar struts, as does the Franklin Olympic engine, in which the piston-pin is located in the upper end of the connecting-rod.

The cast-iron pistons in all General Motors engines other than the Chevrolet are electroplated with a 0.0007-in. tin film for the breaking-in period. Rockne and Studebaker pistons are also tin-plated. The almost "square" cylinder of the Pontiac eight holds the piston travel to the extremely conservative limit of 1885 ft. per mile.

Most of the manufacturers are now using 1/8-in.-wide compression rings, thereby reducing friction because the desired unit pressure can be obtained with less outward radial pressure than in the case of a wider ring. Furthermore, the narrow rings do not wear barrel-shape on the periphery as a result of rocking-action of the piston. Some companies are using even 3/32-in. rings with apparently very successful results. The commercial-car-engine builders were the last to adopt the narrow compression rings and most of them have discontinued the wide type.

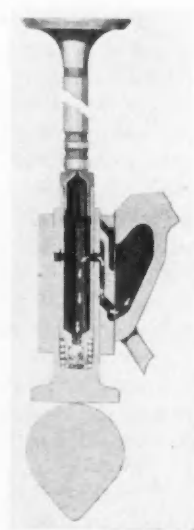


Fig. 3—Pierce-Arrow Hydraulic Valve-Lifter Showing Complete Cutaway Assembly

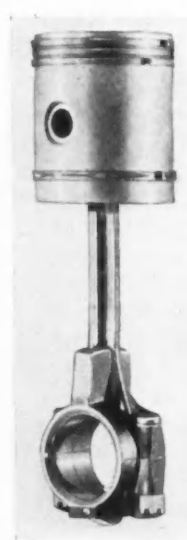


Fig. 5—Pontiac Piston and Connecting-Rod with Center-of-Gravity Adjustment

Use of Four Rings Increasing

A definite trend toward the use of four piston-rings is noted. It has not been possible to get low oil consumption with one oil-control ring, and most manufacturers have gone to the use of two, with a ring at the bottom of the piston in several instances. It is interesting to note that the Chrysler engines have five rings. The Sealed Power Corp. has placed wider oil-vent slots in its Super-Dranoil rings to permit free circulation of oil back to the crankcase. It has increased the "plus circularity"—the diameter from the slot to the back of the ring being greater than the diameter measured at right angles thereto—to insure maximum efficiency in high-compression engines. This idea was originally advocated by this company, which found that above 2600 r.p.m. the blow-by increases rapidly and believes that at some point the vibration of the engine synchronizes with the natural period of the ring, so that the latter leaves the cylinder wall, and combats this by increasing the tension and circularity of the compression rings.

Sectional "hydraulic" rings, which consist of two sections with adjacent faces machined to provide a circumferential groove between them, have been introduced by the Wilkening Mfg. Co. With a two-section design, two independent scraping edges are presented to the oil film on the cylinder wall. The lighter section of each half makes it more flexible and capable of adapting itself to variation from true roundness in the cylinder. In one design the edges are formed at an acute angle and the scraping action packs the groove with oil, providing a literal hydraulic seal.

The Perfect Circle piston-expander for split-skirt pistons, while made for the replacement field, is a develop-

ment worth mentioning. An epic in piston-ring literature is the recent Teetor and Bramberry paper[1] on devices to determine the smoothness of cylinder-wall finish and the radial wall pressure of rings. The entire Chrysler group continues with Tungtite compression rings.

Refinements in Connecting-Rod Practice

There is a distinct trend toward the use of replaceable liners for the connecting-rod big end, consisting of thin-walled, steel-backed, babbitt-lined bushings. They are used by Stutz, Willys, Oldsmobile and the Chrysler groups. This movement is really the adaptation of main-bearing practice to connecting-rods. The rods are diamond-bored to assure accurate fitting, which procedure is also used in the upper hole for the piston-pin bushing. The shells are sometimes copper-plated to prevent corrosion from crankcase fumes. In the Dodge engines the connecting-rods, caps, pistons, rings and pins are matched in sets in which the variation in weight is held down to 0.32 oz. Chevrolet pistons are held to within 1/8-oz. variation. An increasing tendency is to hold close weight-limits in the individual parts and thus do away with selected assemblies. The Pontiac has a distinctive rod, shown in Fig. 5, on which a weight boss on the bottom of the bearing cap provides for center-of-gravity adjustment and another above the big end allows adjustment of over-all weight to the limit of plus or minus 1/16 oz. High speeds, with the accompanying high inertia-forces, demand more scientific balancing. Also, with replacement in the field, balance is preserved in all the reciprocating sets.

The big-end babbitt is centrifugally cast by the Chevrolet company. A new design of cap-bolt head allows milling the flat on the connecting-rod at a greater distance from center, making a stronger juncture between the rod portion and the big end and thereby preventing flexure and cracking of the babbitt. Hercules has introduced a new engine series on which the integral connecting-rod bolts are hollow-milled. Franklin continues with duralumin rods.

Crankshaft and Crankcase Practice

Heavier crankshaft cheeks in the Chevrolet are compensated for by a narrower pin and center bearing, the pins being increased in diameter. The maximum static out-of-balance of each end is maintained below 1/2 oz-in. Dynamic unbalance of the shaft is entirely eliminated by maintaining the static unbalance of both ends in the same plane. The flywheel web has been increased in thickness and blends more gradually into the rim for clutch-heat dissipation. The total permissible out-of-balance of the flywheel is also held within 1/2 oz-in. The harmonic balancer is heavier, with a greater number of lighter leaf springs, and is tuned to a frequency of 135 to 150 cycles per sec. The oil-pan flange surface is made more rigid by the addition of narrow embossed beads which blend with the bolt-hole bosses. Unit pressure on the gasket is increased on the raised surface, assuring greater tightness.

Employment of steel-backed interchangeable liners, assembled without subsequent reaming, is the prevailing practice, as is the use of an air-cleaner cap on the oil-filler tube to prevent dust or grit entering the crankcase. The Franklin Olympic seven-bearing crankshaft is provided with 12 counterweights. With overlapping pins and main journals, the Pontiac shaft is very rugged. In the Waukesha Full Power crankcases, a box-type base rib extends along each side.

[1]See S. A. E. JOURNAL, August, 1932, p. 323.

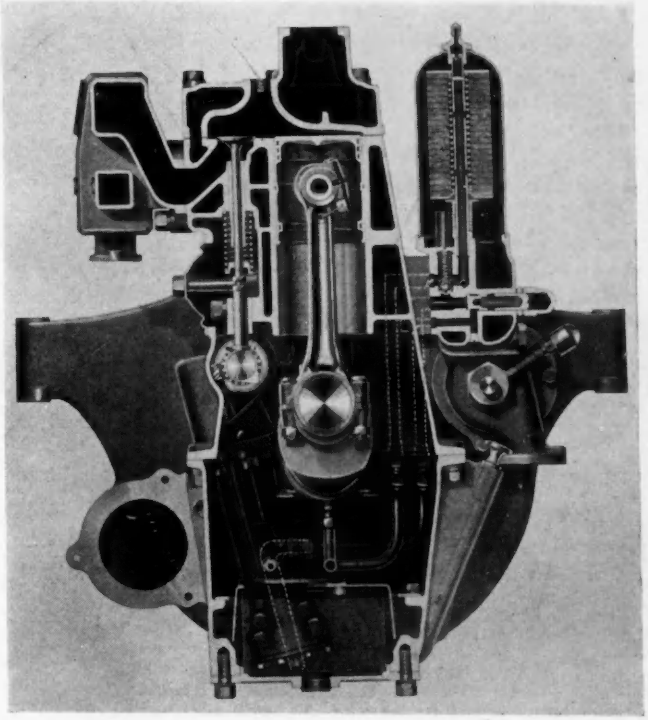


FIG. 4—HERCULES ENGINE, SHOWING AMPLE VALVE-COOLING

Tendencies in Lubrication Methods

Pressure lubrication of the dry-sump type is used in the White 12-cylinder engine. The actual sump or reservoir is built over the crankcase and oil is permitted to leak from the sump through the oil-pump to the crankcase when the engine is standing long enough to get cold. When the engine is first started, the connecting-rods dip into the oil and give immediate excess lubrication to the cylinders and pistons. In less than 1 min. after starting, the scavenging pumps, of which there are two, remove all oil from the crankcase and the pressure pump then takes the oil from the overhead sump and passes it through the double oil-cleaner and a large-capacity oil-cooler.

Chevrolet and Hudson still maintain splash lubrication, whereas Ford, Willys and Plymouth have full-pressure lubrication to all bearings except the piston-pins. Pontiac has force feed to the pins. Willys continues with the Float-O oil intake, and Auburn has adopted it. The Viscon oil-temperature regulator is now used on the G.M.T.-400, the Reo-eight truck, Hupp-eight and Pierce-Arrow engines. The use of this unit on the Franklin-12 is of interest, being located in the cooling-air stream. The oil-temperature regulator has been left off of the Oldsmobile this year.

Crankcase ventilation is continued by all who previously incorporated it, utilizing the air circulation to help cool the oil in the crankcase. Pierce-Arrow cars have a full-flow filter. Besides the Cadillac V-12 and V-16, the Cuno filter is used on the Auburn-12 and the Reo-eight truck engines.

Cooling Systems Made More Efficient

Increased engine outputs and higher speeds have called for greater radiator capacities. The Buick company has abandoned radiator shutters and places a thermostat in the top tank, with a bypass pipe following the right back contour of the core. A spring-loaded bypass is located in the top of

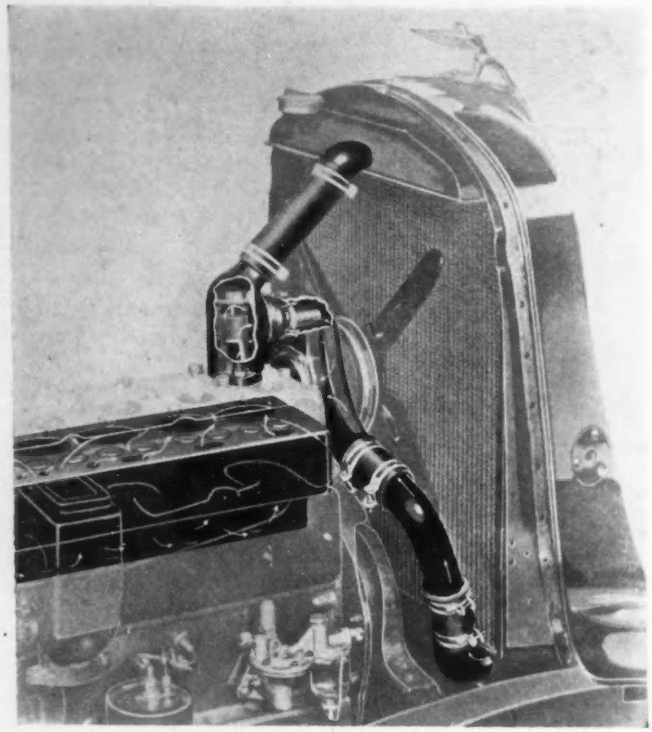


FIG. 6—OLDSMOBILE THERMOSTATIC WATER-HEAT CONTROL WITH BYPASS VALVE ABOVE PUMP

the Oldsmobile water-pump body at the front of the engine, as shown in Fig. 6. Water, reaching the closed thermostat in the cylinder header, exerts pressure on the bypass valve, forcing it open. Recirculation is established through the water manifold at the left side of the block. The Oldsmobile water-pump has a ball-thrust bearing. Pontiac maintains its cross-flow radiator, and cool water from the pump travels through a "pipe line" extending the length of the engine between the cylinder walls and the valve-stem bosses. Holes adjacent to each exhaust-valve boss and passage distribute the water.

The White-12 water-pump is of the single-stuffing-box type and has an automatically lubricated impeller thrust bearing, while the pump-shaft bearing is lubricated by water from the high-pressure side of the pump. Buick uses a case-hardened water-pump shaft, while the Waukesha Full Power line uses nitralloy. In the Terraplanes the Hudson company is using a water-pump for the first time in its small models, combining it with the fan. Franklin uses a Sylphon thermostat to operate the "radiator" shutters. The Plymouth and Dodge engines have the water-pump seal maintained by spring pressure, thereby eliminating the manual adjustment.

Unequal angular spacing of the blades to break up the frequency of the fan vibrations is still in favor, the latest convert being the Chevrolet company, whose four-blade fan is offset 15 deg. The De Soto fan has four blades, with a 40-deg. stagger from equal spacing.

V Radiator Now in Vogue

This year there is an unprecedented vogue of the V radiator, sloping forward at the bottom. In most cases the bottom of the radiator contour terminates in a point, with the pointed portion sometimes curved forward. A few radiators are placed ahead of the front axle, thereby giving more body room and simulating English design. The radiator shells of all General Motors groups are painted the same color as the body, to accentuate hood length. Other than in Chevrolet, the contrast is furnished by a chromium-plated grill which, in the case of Buick and Cadillac, is of close-mesh construction. Five-per-cent greater cooling efficiency is obtained by Cadillac through a new louver center-construction of the core, air being deflected through and around the cooling fins instead of passing straight through. The Cadillac radiator cap is now under the hood on the oil-level-gage side, the shutters are unchanged and the V-16 water-pump is provided with a floating bushing and a new double packing. Graham has a thin chromium fin-keel at the top of the radiator in place of an ornament. On the Auburn eights, vertical fins of stainless steel are used for ornamentation, while on the 12's they are horizontal. The shell opening is outlined with a chromium-plated trim molding.

Fuel Temperature Automatically Controlled

Considerable interest is centered in the Bendix-Stromberg carbureter, in which the automatic choke is continued in revised design and supplemented by an automatic idling adjustment whereby the engine idling speed is greater when the engine is cold than when hot. It is used on the Oldsmobile, Studebaker, Packard, Pierce-Arrow and the Reo Flying Cloud. A Packard application is seen in Fig. 7. De Soto has an automatic choke-control dependent upon a thermostat and solenoid for its operation.

Manual heat-control of the intake hot-spot is being supplanted by a thermostat. This is used by Chevrolet, Pontiac and the Chrysler group, all with downdraft carbureters. Pierce-Arrow also has adopted downdraft.

In the Buick, automatic heat-control of the Marvel carbureter riser is governed by a thermostat. A tunnel attached to the engine block conveys air from directly behind the fan to the thermostat, located in a housing having a rotary shutter in front. The shutter is interconnected with the throttle, which closes it at low and high speeds but holds it open over the intermediate or driving range. Buick engineers attribute the ability to raise the compression several pounds to the maintenance of correct mixture temperatures. For cars used in territories where extreme dust conditions prevail, a heavy-duty triplex air-cleaner is supplied for Buicks. Automatic heat-control of the Studebaker hot-spot is affected by deflecting all of the exhaust gas thereto through the closure of a weighted valve, also under the influence of a thermostat. After the engine has warmed up and the throttle opened, the pressure and heat of the exhaust open the valve.

The power of the Duesenberg engine has been increased 20 per cent, to 320 hp. This eight-cylinder 3¾ x 4¾-in. engine is provided with a supercharger located slightly above the cylinder head, as shown in Fig. 8. This is 12 in. in diameter, geared at six times crankshaft speed, and at 4000 r.p.m. of the engine maintains a pressure of approximately 8 lb. per sq. in. above atmospheric in the intake manifold. In its Olympic and 12-cylinder cars the Franklin company continues with the supercharging effect obtained by the passage of air from the cooling duct to the carbureter.

Fuel-Cleaning, Carbureter and Electric Pump

In the White 12 there are two downdraft carbureters with oil-wetted-type air-cleaners located in a special compartment under the seats. Carbureter adjusting is the only servicing operation necessary from inside the body. The Chevrolet accelerating pump does not discharge beyond half throttle.

A hot-spotted trap at the center of the manifold floor is raised to catch any fuel particles thrown out of the mixture stream. The manifold inclines with D-shaped branches to the end valve ports, while the center branch is flattened to provide equal distribution, also aided by the depending sleeve in the riser. The Decarbonizer is continued in the Oldsmobile.

Stewart-Warner has introduced an electric double-acting fuel-pump conntected with the ignition circuit, allowing it to operate when the ignition switch is closed. The Pierce Governor Co. has introduced the Electrovac, which is used in the Reo-eight truck. The manifold vacuum closes the governor butterfly under the control of an electromagnetic valve. A small centrifugal unit is mounted on the distributor shaft below the rotor, being calibrated for the desired speed. There is no loss of power and extremely close speed regulation is possible. A spacer ring between the distributor body and cap makes up the added length taken by the centrifugal unit.

A number of cars have the filler cap on the left side so that the fuel tank can be completely filled when the roadway is crowned. The filler on the Pierce-Arrow is in the center of the left rear fender crown and acts as a bracket for the characteristic Pierce-Arrow tail, stop and backing-light unit. Studebaker has a similar filler supporting the stop taillight. On the Buick, longitudinal ribs are pressed into the top and bottom of the tank to prevent flexing and consequent noise. The White city-type bus has a 100-gal. tank under the floor at the rear, thereby obviating frequent refueling.

Exhaust-Muffler Types and Mounting

Mufflers of the straight-through type, with perforations in the central pipe opening into a series of surrounding resonance chambers, are used on the Buick and Pontiac. The Buick exhaust manifold has two sleeve-type joints to allow for expansion and contraction. Pierce-Arrow has two straight-through mufflers, also with resonance chambers. Chevrolet has a tuning chamber at the front and rear ends of the muffler, which, with the tail pipe, is resiliently mounted in brackets having a rubber cushion. The Willys four and six and all Auburns have a rubber-insulated exhaust system.

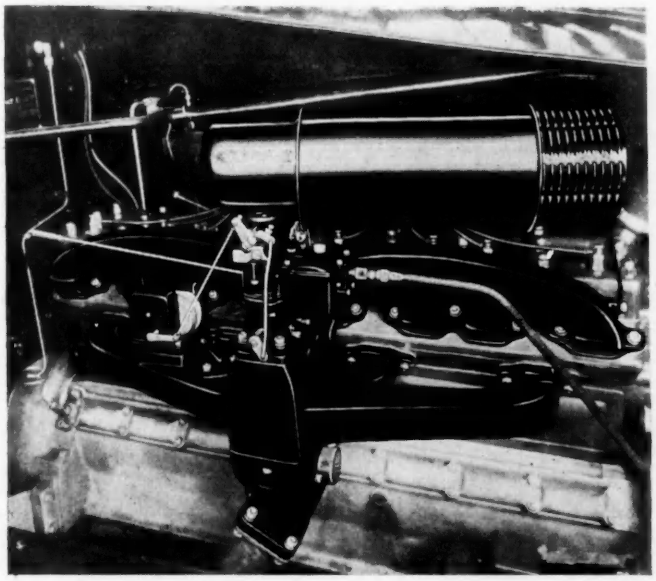


Fig. 7—Bendix-Stromberg Carbureter and Automatic Choke-Control on Packard-Eight Engine

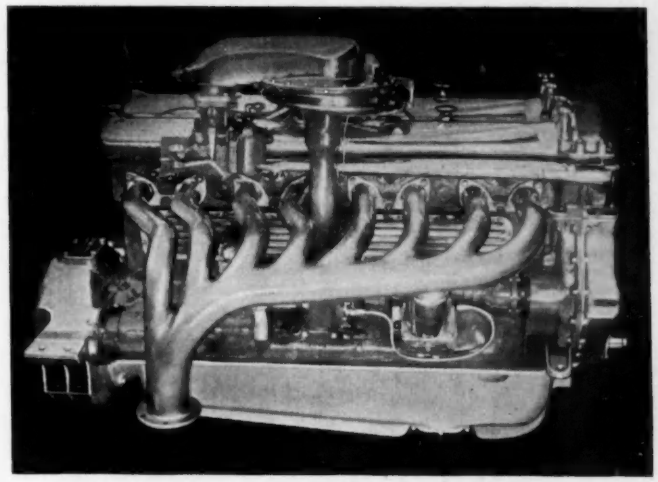


Fig. 8—Duesenberg 320-HP. Supercharged Engine

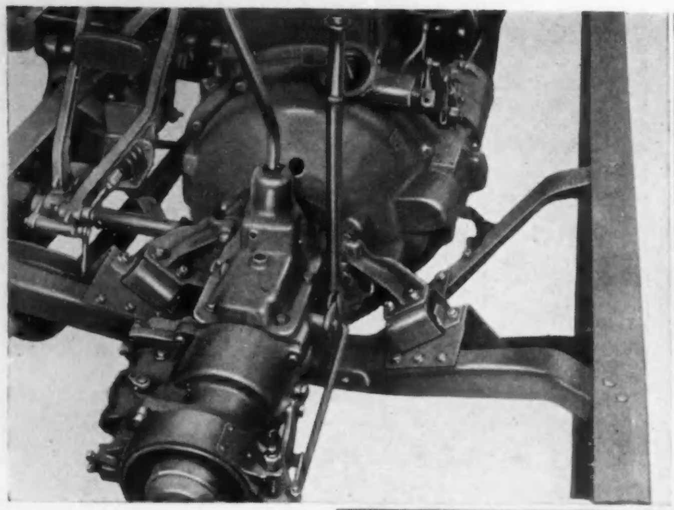
The White-12 exhaust manifold is cast integral with the cylinder blocks on the under side, eliminating heating of the coach floor. All exhaust joints, of which there are a considerable number, are made up with full flanges welded to the pipe, and copper-asbestos gaskets are used to prevent gas leakage under the floor. The Titeflex Metal Hose Co. is using a heat-treated copper-wire packing in the full-interlock seam of its flexible tubing. Mack and A.C.F. use it for exhaust pipes and connections. The all-metal construction gives high heat-resistance and allows fittings to be brazed or welded thereto.

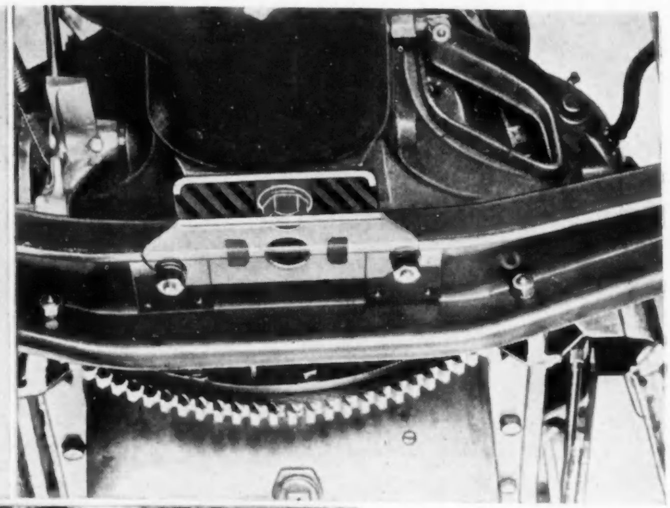
Advances in Starter-Operating Mechanism

In keeping with other simplifications of control, advances have been made in the starter-operating mechanism, all sponsored by Delco-Remy. Chevrolet utilizes a vacuum control-diaphragm to connect the starter mechanism with the accelerator rod when the engine is not operating and no suction exists in the intake manifold. Depression of the accelerator operates the starter. When the engine operates, the manifold suction disconnects the starter control by deflecting the diaphragm, after which the accelerator pedal operates on the carbureter throttle in the usual way.

On De Soto and Chrysler six-cylinder models, the selector type of starting-motor control is employed. A movement downward on the accelerator pedal, as far as it will travel, shifts the starting-motor pinion into mesh, closes the starter switch and opens the throttle to the desired adjusted amount for starting. When the engine starts, and with pressure on the accelerator pedal momentarily released, the vacuum-operated diaphragm in the selector causes the pedal to function then only as a throttle. This throttle connection remains as long as the engine continues to run.

The Chrysler eight-cylinder cars again employ the accelerator pedal for starting the engine, along with its regular throttle function. After closing the ignition switch, the first movement of the accelerator closes the switch contacts enclosed in the Delco-Remy vacuum switch. Current then flows through the control relay on the generator and through the generator to ground, closing the relay contacts. The solenoid shifts the pinion into mesh, closes the starter switch and the starting motor starts the engine. It is possible to open the throttle any desired amount while cranking. As the engine fires and comes up to speed, either the vacuum in the intake





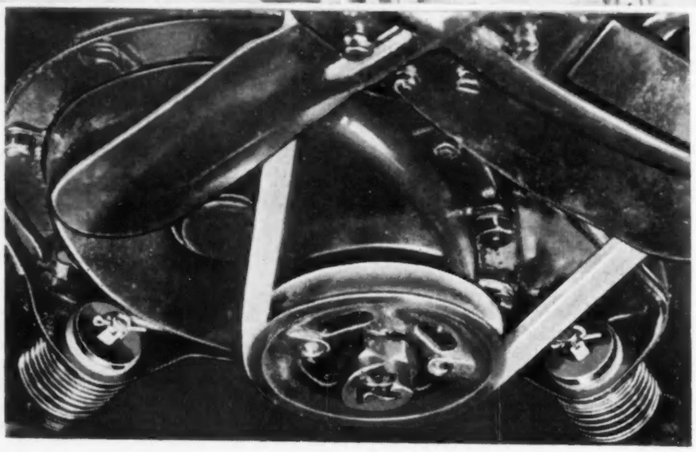


FIG. 9 — GRAHAM-ENGINE REAR MOUNTING

FIG. 10 — HUDSON REAR ENGINE-SUPPORT, SEEN FROM BELOW

FIG. 11—CONTINENTAL FRONT ENGINE-SUPPORT

manifold or the generator voltage, or both, stops the current flow through the relay coil, thus opening the contacts and releasing the solenoid and the starter switch. The pinion is then shifted out of mesh by action of the pinion spring, and the accelerator pedal begins functioning as a throttle.

Buick and Pontiac use a button, which, when pressed, energizes a solenoid mounted on the starting-motor housing, which in turn engages the pinion. The starter cannot be engaged unless the ignition switch is turned on. In the Plymouth, the starter pedal is above and in line with the accelerator treadle, so that the former can be depressed by the toe and the latter by the heel to the desired extent.

With the increased demand for energy due to 32-cp. headlamps, added spot-lights and radio equipment, larger generators are being provided.

Vacuum Control of Ignition Distributor

Startix is still popular and has been improved by a secure flanging of the housing and the cover and the addition of holes in the bottom to allow drainage of any water that might accumulate. A single breaker-arm of faster design is used on the Chrysler, Graham, Pontiac and Buick eight-cylinder engines. It eliminates the necessity for synchronization when two arms are used.

In the Mallory distributor, two circuit-breakers are used to increase the dwell so as to build up coil saturation, one breaker closing in advance of the other. As soon as the first closes, the coil starts to build up. When the first breaker opens, the circuit is still held closed by the second, and the spark does not occur until the second breaks. Since the one breaker does all the timing of the engine, it is not necessary to synchronize the two.

Based on the premise that with low compression the mixture is much slower burning than with high compression, and if the spark is not further advanced when the compression is low, loss of power will ensue, Mallory has developed a vacuum control in addition to the regular centrifugal advance. As the weights fly outwardly, pins therein advance a cam plate by engaging diagonal slots therein. A piston, under the influence of a spring, presses a brake-shoe against the rim of the cam plate when the vacuum is low and contracts the centrifugal governor, retarding the breaker cam and rotor. With a high vacuum, the piston draws the brake-shoe away from the cam plate against spring pressure and does not impede the centrifugal advance.

Developments in Circuit-Breaker Operation

Chevrolet also provides additional spark advance at part throttle by placing the breaker-housing rotation under the control of a diaphragm susceptible to intake vacuum. An "octane selector" at the distributor permits manual adjustment of the advance to compensate for the detonating tendency of the fuel used. Adjustment is made by a large knurled nut and check nut, giving a 10-deg. advance or retard. The stationary bracket is graduated in degrees of flywheel rotation. The coil is mounted on the front side of the dash, and the high-tension side is grounded by the ignition switch.

The Eclipse Machine Co. is introducing a circuit-breaker to be mounted on the intake manifold. It is actuated by back pressure created within the intake manifold, either from back-fire or reversed engine rotation at the time of having a forward gear engaged. It consists of a cylinder and a piston, a thermostatic breaker-device and two sets of contact points, one of which is closed during normal operation, permitting current to flow from the ignition switch to Startix. Intake-manifold pressure forces the piston upward, connecting a point attached to a grounded movable arm and a similar tungsten point on the thermostatic metal strip. This creates a momentary ground in the circuit through the bimetal strip, instantly heating and flexing it and separating the second set points, thereby breaking the circuit from "ignition" to Startix. Continued backward rotation prevents cooling of the bimetal strip and re-closing the circuit.

An entirely new type of Bendix drive has been designed to permit the use of a smaller pinion having nine teeth of 10-12 pitch on a ⅝-in-diameter armature shaft. Another novel feature is the disconnection of the threaded engagement of the pinion with the screw shaft when the pinion is demeshed and the provision for the reestablishment of the connection when starting is to take place.

In the White 12, a separate ignition distributor is mounted on each side of the engine, driven from the camshafts. The fully automatic distributors, the coils, condensers, spark-plugs and ignition wiring are enclosed in dustproof and waterproof housings. Because of the small flywheel diameter, two 12-volt starting motors are used.

The 14-mm. spark-plug continues to replace the 18-mm. size. Pontiac has a wiring manifold even with the top of the left side of the cylinder head, with a short, transverse, exposed portion of each high-tension wire to its plug. Graham uses a perforated manifold to provide ventilation therein.

Changes in Engine Mounting

The floating-power torque spring is now replaced by a pair of live-rubber blocks between the rear of the engine and the intermediate cross-member. The rear support is now above the transmission case, resulting in a lower location for the front mounting. Willys is using floating power on its new four and six. Cadillac utilizes more rubber in the support to give a softer mounting. Buick has a five-point mounting, two at the front, spaced as far apart as the two at the bell-housing, and a fifth one at the rear of the transmission.

In the Pontiac, the rear engine-support bosses are cast on the sides of the crankcase wall ahead of the bell-housing. A five-point rubber mounting, similar to the Buick, is used.

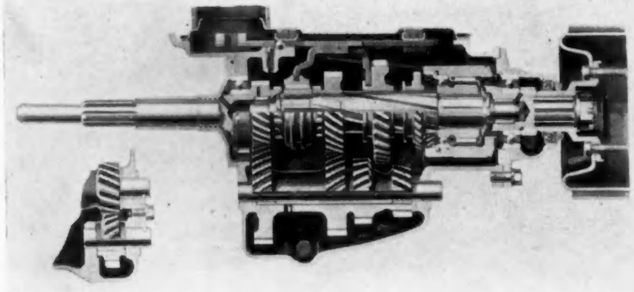


FIG. 13—DODGE TRANSMISSION WITH SLIDING HELICAL GEAR ON A HELICAL SPLINE

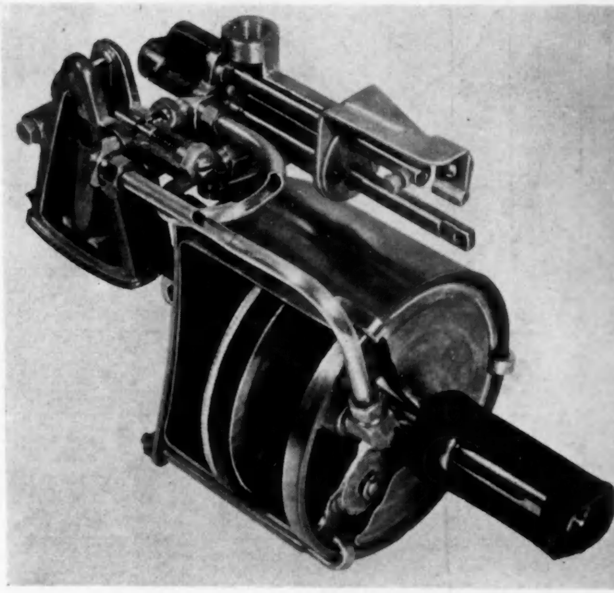


FIG. 12—BENDIX AUTOMATIC VACUUM-CLUTCH CONTROL WITH PENDULUM CUSHION-VALVE

Chevrolet's Sta-Namic balance aims at defeating the rocking motion of the powerplant due to static residue and the tendency of the engine to rotate about itself due to dynamic residue. The four-point diamond-shape mounting is maintained, with a more liberal use of rubber. The side mountings now consist of two castings separated by ½ in. of rubber vulcanized to each at their adjacent faces and around their entire periphery. The faces are at a slight inclination to the horizontal. The right support attaches to the front of the clutch housing, while the left one is further forward and secured to the side of the crankcase, giving a diagonal line of support. The tendency to rock at right angles thereto is more effectively snubbed by the front and rear mountings.

At the rear of the Graham engine an angular rubber mounting is used, as in Fig. 9. This is used on all models except the high-priced eight. Large-diameter rubber discs are placed under each engine foot at the front, with a smaller disc above and a bolt through the assembly to the supporting frame-member. The Oldsmobile has a front rubber support below the water-pump, while the rear end rests on two angularly mounted blocks below the clutch-housing. A line through the supports passes through the center of gravity of the engine. On all models of the Hudson two air-cushioned rubber biscuits support the engine at the front, with the third rubber support under the clutch-housing, as shown in Fig. 10. Auburn uses a four-point air-cushioned rubber mounting, the two front cushions being supported on the A-frame-members and the rear attaching to a bracket on the milled rear face of the bell-housing at each side. Welded supports are to be found on the Hudson and Chevrolet.

The Continental engines have a modified Borg-Warner mounting with rubber in the rear at the transmission and two coiled springs with rubber inserts at either side of the engine in front, disclosed in Fig. 11. A great deal of research was conducted to determine the best angle of these mountings. The exact neutral axis of all three engines was determined by balancing tests, and then the two mountings were placed so that lines projected through their axes intercepted at a point on the neutral axis, which also passes through the rear mounting.

TABLE 2—CLUTCH AND TRANSMISSION DATA

CAR	MODEL	CLUTCH: MAKE	CLUTCH: No of Discs: Driving[a]	CLUTCH: No of Discs: Driven	CLUTCH: FACINGS: Material	CLUTCH: FACINGS: Diameter In.	CLUTCH: FACINGS: Thickness, Ins.	CLUTCH: FACINGS: Number Used	CLUTCH: Power Operated	TRANSMISSION: Make	TRANSMISSION: RATIO IN: Second	TRANSMISSION: RATIO IN: Low	TRANSMISSION: RATIO IN: Reverse	TRANSMISSION: Gear Type	TRANSMISSION: Synchronisation, High and Second	TRANSMISSION: FREE-WHEELING: Make	TRANSMISSION: FREE-WHEELING: Location
Buick	50	Own	1	1	....	9½x6¼	9/64	2	B-K	Own	1.737	2.895	3.474	Helical[c]	Yes		
Buick	60	Own	1	1	....	9⅞x6¼	9/64	2	B-K	Own	1.737	2.895	3.474	Helical[c]	Yes		
Buick	80, 90	Own	3	2	....	9 x6½	9/64	4	B-K	Own	1.714	2.829	3.536	Helical[c]	Yes		
Cadillac 8 and LaSalle	345C, 355C	Own	3	2	Woven Asbestos	10 x5½	9/64	4	Optional B-K	Own	1.47	2.40	2.49	Helical[d]	Yes		
Cadillac 12	370C	Own	3	2	Woven Asbestos	10 x5½	9/64	4	Optional B-K	Own	1.47	2.40	2.49	Helical[d]	Yes		
Cadillac 16	452C	Own	3	2	Woven Asbestos	11 x6½	9/64	4	Optional B-K	Own	1.47	2.40	2.49	Helical[d]	Yes		
Chrysler 6	CO	Borg & Beck	1	1	Molded Asbestos	9⅞x6¾	9/64	2	B-K	Own	1.49	2.59	3.24	Helical[e]	No	Own	Rear of Transmission
Chrysler 8	CT	Borg & Beck	1	1	Molded Asbestos	9⅞x6¾	9/64	2	B-K	Own	1.49	2.59	3.24	Helical[e]	No	Own	Rear of Transmission
Chrysler Imperial 8	CQ	Borg & Beck	1	1	Molded Asbestos	9⅞x6⅛	9/64	2	B-K	Own	1.49	2.59	3.24	Helical[e]	No	Own	Rear of Transmission
Chrysler Imperial Custom 8	CL	Borg & Beck	1	1	Molded Asbestos	11 1/16x6⅛	9/64	2	B-K	Own	2.48[b]	3.63	3.14	....	No	Own	Rear of Transmission
De Soto	SD	Borg & Beck	1	1	Molded Asbestos	9⅞x6¾	9/64	2	B-K	Own	1.49	2.59	3.24	Helical[e]	No	Own	Rear of Transmission
Dodge 6	DP	Borg & Beck	1	1	Molded Asbestos	9 x5¾	9/64	2	B-K	Own	1.55	2.81	3.61	Helical[e]	No	Own	In Transmission
Dodge 8	DO	Borg & Beck	1	1	Molded Asbestos	9⅞x6¾	9/64	2	B-K	Own	1.49	2.59	3.24	Helical[e]	No	Own	Rear of Transmission
Graham	Standard 6	Long	1	1	Molded Asbestos	9¼x5½	9/64	2	None	Warner	1.605	2.82	3.38	Helical[c]	Yes	Warner	Rear of Transmission
Graham	Standard 8	Long	1	1	Molded Asbestos	9¾x5½	9/64	2	None	Warner	1.646	2.864	3.437	Helical[c]	Yes	Warner	Rear of Transmission
Oldsmobile 6	F33	Borg & Beck	1	1	Composition	9⅞x6⅛	⅛	2	Optional B-K	Own	1.66	2.90	3.67	Helical[c]	Yes		
Oldsmobile 8	L33	Borg & Beck	1	1	Composition	9⅞x6⅛	⅛	2	B-K	Own	1.66	2.90	3.67	Helical[c]	Yes		
Pierce-Arrow	836	Long	3	2	Molded Asbestos	9¾x6¼	9/64	4	None	Own	1.70	2.83	3.40	Helical[e]	Yes	Warner	Rear of Transmission
Pierce-Arrow	1236	Long	3	2	Molded Asbestos	9¾x6¼	9/64	4	None	Own	1.70	2.83	3.40	Helical[e]	Yes	Warner	Rear of Transmission
Plymouth	PC	Borg & Beck	1	1	Molded Asbestos	9 x5¾	9/64	2	Optional B-K	Own	1.55	2.81	3.61	Helical[e]	No	Own	In Transmission
Studebaker 6	56	Long	1	1	Molded Asbestos	9¼x5½	9/64	2	None	Warner	1.646	2.864	3.437	Helical[e]	Yes	Warner	Rear of Transmission
Studebaker Commander	73	Long	1	1	Molded Asbestos	9¼x5½	9/64	2	None	Warner	1.646	2.864	3.437	Helical[e]	Yes	Warner	Rear of Transmission
Studebaker President	82	Long	1	1	Molded Asbestos	9¾x5½	9/64	2	None	Warner	1.646	2.864	3.437	Helical[e]	Yes	Warner	Rear of Transmission
Studebaker President	92	Borg & Beck	1	1	Molded Asbestos	11 1/16x6⅛	9/64	2	None	Warner	1.646	2.864	3.437	Helical[e]	Yes	Warner	Rear of Transmission

[a] Flywheel is not included as a driving disc. [b] Third-speed ratio 1.38:1. [c] For countershaft drive and second-speed gears. [d] For all gears except reverse. [e] For all gears.

Improvement in Clutch Mechanisms

Borg & Beck have developed a line of flexible center-driven clutch plates in which the cushioning springs are retained in their pockets by half-round wires passing through them and replacing the former tabs. This allows the use of a larger spring in the same space and has reduced the stresses so that spring breakage is asserted to be unknown. In some assemblies the cushioning springs are located in pockets of equal length in the hub member but alternately of unequal length in the driven plate and retainer members which enclose the hub. One end of each spring makes contact with both the hub and the driven clutch members in the initial or undeflected position, whereas each alternate spring makes contact with the hub member only in the undeflected position, a slight clearance being allowed between the ends of the springs and the driven members.

This arrangement provides the full load-carrying capacity of all springs for carrying the engine torque during acceleration, but only half of the springs are initially active for carrying deceleration torque when the car is driving the engine. Only part of the angular travel of the plate is carried by half of the springs, by coming into action before the plate is deflected to the end of the stop-pin slots.

This has been found valuable in damping drift or acceleration rattles in the transmission, especially in sensitive installations where it is not possible to dampen out the rattles with driven discs having the same deflection characteristics in the forward as in the reverse direction of torque.

The Powerflo clutch has been taken over by Brown-Lipe and redesigned so that the weights and all adjustments can be assembled or reached from the transmission side of the flywheel. One truck manufacturer will shortly announce a fluid clutch for use where continuous stopping and starting is involved.

Pendulum-Operated Clutch Control

The Bendix clutch control has been redesigned so that the operating valve, often used on the intake manifold or separately, is now a unit with the operating cylinder. To this unit has been added a cushion control-valve, shown in Fig. 12, consisting of a pendulum that swings parallel to the longitudinal axis of the car. As it passes on either side of the normal position, it operates a small cut-off valve in the

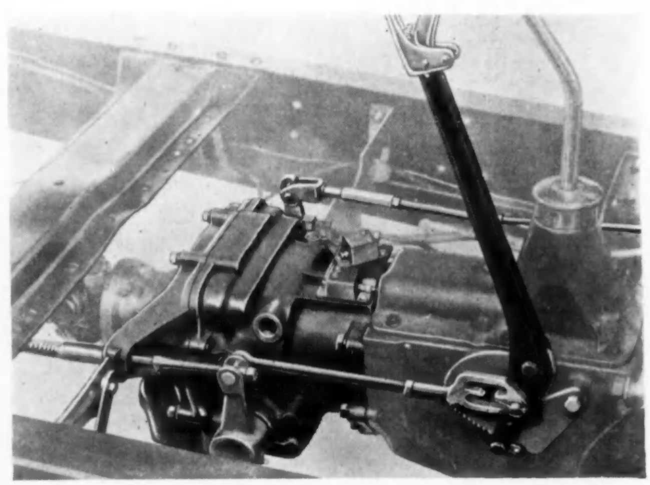


Fig. 14—Pierce-Arrow Transmission with Free-Wheeling Unit and Stewart-Warner Brake Servo

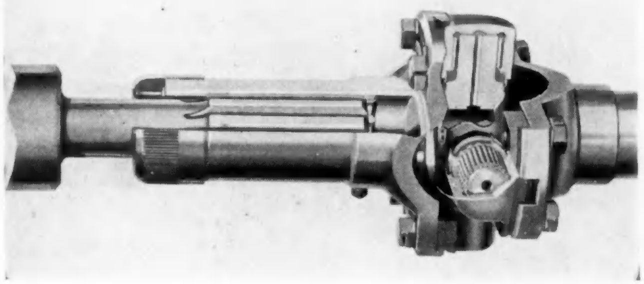


Fig. 15—Mechanics Universal-Joint

bleeder line from the cylinder to the bleeder slot on the accelerator control-valve. It smooths out clutch engagement, prevents jerking and facilitates production by allowing more variation in the slots of both the control valve and the piston-rod of the cylinder. A spring holds the valve wide open, and when at rest the pendulum is about 12 deg. forward of vertical. The Cadillac company has continued the automatic clutch control, termed "controlled free-wheeling", only as optional equipment on the new cars. It is also furnished as optional on the Oldsmobile.

All of the Chrysler-group cars have a control for the automatic clutch and free-wheeling unit that is arranged so that one can drive in conventional, free-wheeling or both free-wheeling and automatic clutch-actuation. Bendix-Westinghouse has an air clutch-control unit, eliminating linkage between the pedal and the clutch throw-out shaft and also decreasing the exertion necessary for operation. It is used on the General Motors bus and by White, and in the latter actuates a wet-type clutch with all moving parts automatically lubricated.

Clutch and transmission data of some current models are given in Table 2.

Design Changes in Transmissions

All transmission gears, including the reverse idler, are of the helical type in the Chrysler, Dodge, Plymouth export model and the Continental cars. The countershaft drive and second-speed gears are in constant mesh and the light clutch member facilitates shifting effort and lever travel. The clutch teeth on the gear hubs are alternately undercut, and in the sliding clutch member alternate teeth are entirely omitted. The low and reverse gear slides on a helical spline, as shown in Fig. 13, whereby the tendency of the gear to creep is neutralized by the thrust of the spline. This is the first instance of a sliding helical gear with thrust elimination and is a noteworthy accomplishment.

The plain-bearing countershaft is now obsolete, antifriction bearings being used throughout. In some instances a countershaft and reverse idler are mounted on needle bearings to take the place of bushings. The Chevrolet has helical gears for the constant mesh in second-speed sets. The Buick transmission remains unchanged except that the detents in the shifting mechanism have been changed from plungers to balls, eliminating the tendency to stick. The Buick and Graham gearshift-lever ball is of soft instead of hard rubber to prevent transmission of vibration to the body.

The Hudson Terraplane has an interesting design in which the over-all length and movement of the shift lever have been shortened. The first and reverse sliding gear is on the countershaft. The second-speed main-shaft gear is mounted loosely on an extension of the transmission main-drive gear. Both have internal gear-teeth, engaged by a shifting member with external teeth. A babbitt-lined steel tube, pressed into the second-speed gear, acts as its bearing. A similar babbitt bearing is used for the countershaft and reverse idler. In the Plymouth, Dodge and De Soto transmissions the shifting rods are made of bar stock, with the forks projection-welded to them. The Chrysler Imperial Custom has a four-speed transmission and is the only one to retain the internal-gear construction.

In the White bus, hardened and ground helical gears are used for all four forward speeds. Extra bearings on the main and countershafts prevent shaft deflection. Two cross-arms mounted in rubber support the transmission housing, the forward one having a trunnion mounting to form a three-point support. Reverse is through spur gears.

Increase in Speed Changes

A four-speed unit has been taken by Brown-Lipe as a basic design and, by bolting a supplementary unit to the rear thereof, has been converted into a 5, 8 or 12-speed transmission. This company has also introduced the "synchro-shift", consisting of a vacuum cylinder at the rear of the transmission which controls a clutch and free-wheeling unit. Whenever the clutch pedal is depressed, the rear end of the transmission is disconnected and a clutch brake at the front of the transmission quickly slows down the gears so that shifting is very easy.

The Clark Equipment Co. has brought out a line of five-speed transmissions, coincident with the demands of tractor-trailer service, in both overdrive and underdrive types. Gears are of the constant-mesh helical type in the two top speeds. Some of the models are provided with a separate spur take-off gear on the countershaft to the rear of the helical forward gear. The reverse reduction in the underdrive type is higher than in the overdrive, thus providing a reverse in which racing the engine to back up the truck is not necessary. A completely sealed gearshift mechanism is obtained by keeping all shifting bars within the cover housing. Heavy exterior ribbing on the case characterizes these transmissions.

A few months ago, when some manufacturers thought that the popularity of free-wheeling was waning somewhat,

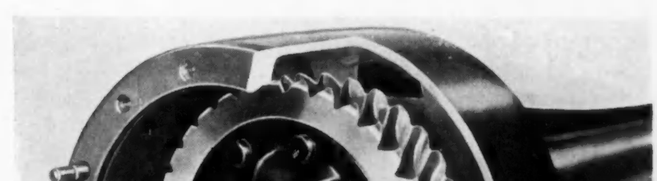


Fig. 16—Pierce-Arrow Worm-Drive Rear Axle

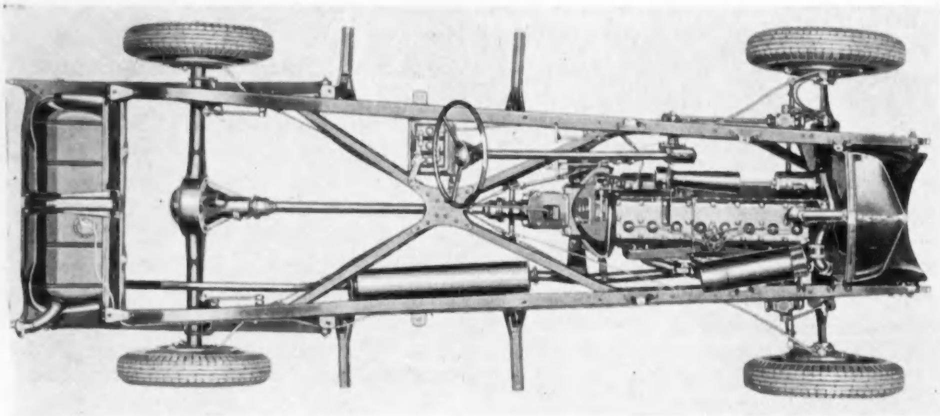


FIG. 17—OLDSMOBILE-EIGHT CHASSIS, SHOWING SHORT BRAKE CROSS-SHAFT WITH DIAGONAL BRAKING

they considered its omission from low-priced models as an economy measure. These same companies are, however, continuing with the free-wheeling unit, evidently feeling the need of it even on cars produced under an extreme-economy régime. The Oldsmobile, Willys four and Continental do not include it. The roller-rachet type is continued in the same forms. Some of the Chrysler-group cars have the free-wheeling unit entirely within the transmission, and the locking member is mounted on the spline of the main shaft. Where the helical spline is used, helical teeth are provided on the locking member. A larger number of rollers are used.

In the L.G.S. free-wheeling units, the single-pocket type of design is used because of its greater simplicity and strength over the double-pocket type. These units are used in the Duesenberg, Chevrolet and Auburn. In the Pierce-Arrow cars, the free-wheeling housing is extended to incorporate the Stewart-Warner braking mechanism, as shown in Fig. 14.

Needle Bearings in Universal-Joints

There has been an avalanche toward the use of needle bearings in universal-joints. The Mechanics Machine Co. provides a companion flange serving as a yoke and thereby shortening the over-all length, as will be seen in Fig. 15. Drive is transmitted from the yoke to the bearing unit by an integral key, thus removing the driving load from the bolts, and tests have proved that they will not loosen. The outer flanges of the bearing units are ground to a spherical form and fit under mating lips on the yokes. Every part of the joint is machined except the ring portion of the cross, making for better balance.

Spicer has produced a joint in which an interchangeable bearing-unit is used so that needle or plain bearings can be provided. Over-all length has been reduced in this joint by inserting the journal crosses in the yokes in a tilted position, followed by centralizing them with the insertion of the bearing units.

The Universal Products Co. has improved its pin-and-ball joint by placing needle bearings between the pin and ball. A centering block in each end of the pin does away with the old method of centering by means of a ball head. A plate has been added to the rear of the joint, holding the compensating spring in place and also sealing the lubricant in the joint, making it a self-contained, complete assembly unit. This joint is used in the Plymouth, Dodge and De Soto. Pierce-Arrow and Studebaker use a split-yoke member which holds four thimbles containing needle bearings. In the case of Pierce-Arrow, the propeller-shaft is made of larger-diameter tubing than formerly to assure freedom of vibration at the higher speeds these cars now possess.

The Baker Wheel & Rim Co. has a ball-bearing joint with two rows of balls working in a spherical cup. The plane of the inner row lies just beyond the center of the sphere, and the other row is outside of the first. Blood Brothers use bronze thrust washers with graphite impregnation as a protection against lubrication failure. The bronze liners are similarly treated. The sliding fit of the Continental front universal is made part of the transmission to insure lubrication therefrom.

Rear-Axle Worm Drive Revived

Revival of the worm drive is interesting, being sponsored by Pierce-Arrow, with tapering side members bolting to a center housing, as in Fig. 16. Last spring Nash introduced a model with this drive in which the splint-mounted worm wheels are heated in boiling water before assembly, then cold riveted to the carrier, the rivet heads bearing on the carrier flanges and not on the bronze. Worm adjustment is by means of shims. An oil distributor is used in the form of a sleeve surrounding the worm except where it makes contact with the wheel.

The Franklin 12 offers optional choice of the use of a two-speed rear axle, constructed the same as that used by Auburn. The control of both is different than in last year's Auburn, however, in that pre-selection of ratio is possible by setting the dash control to the desired position, whereupon the shift is made the next time the clutch pedal is depressed. Hupp continues the use of hypoid gears in all models.

Axle Weights Being Decreased

In the Terraplane, reduced diameter of the driving shafts is obtained by decreasing the overhang for the outer axle bearing. This is made possible by the use of a wire-wheel hub of such large diameter that the 9-in. brake-drum is nested partly within it. The Willys four has the same arrangement. Rigidity of the Terraplane housing is accomplished without weight increase by welding the rear coverplate to the center housing. This method is also used in the Dodge. A definite trend toward decreasing rear-axle weights is evident.

A torque-tube construction is used in the Pontiac, and in the Cadillacs an oil retainer is placed between the torque tube and the differential carrier to prevent rear-axle lubricant

leaking into the tube and eventually into the transmission, in localities where steep hills are encountered. Chevrolet now provides a one-piece malleable-iron differential housing and ring-gear flange. In the Pontiac and Chevrolet the wheel-hub flange is forged intergral with the shaft, replacing the former taper. The outer bearing is now a Hyatt roller, closer to the wheel and with a coil-spring leather seal. The axle shafts are retained within the differential by means of C-washers that fit into a counterbore on the inside face of the differential side-gears. Hudson uses Bakelite washers for them. No bearing caps are used on the carrier, a solid construction being provided. The Willys four has a straddle-mounted pinion and a malleable-iron center with riveted and shrunk-in tubes.

The trend toward a wide track continues with those manufacturers who have not previously increased it.

The White city bus has a double-reduction axle, with a spiral-bevel unit in the center of a one-piece axle-housing and a herringbone-gear reduction in housings at the wheel ends of the axle. Large oil capacity and a free flow of oil throughout the entire axle, together with a large radiating surface, result in low oil and gear temperatures.

Smaller Diameter and Wider Brakes

There has been a tendency to wider brakes with smaller diameters, due to the trend toward smaller wheels. For instance, the Packard company has changed from 16x2 to $15\frac{1}{8}$x$2\frac{1}{2}$-in. and from 15x$1\frac{3}{4}$ to 14x$2\frac{1}{4}$-in. The use of cast iron has permitted smaller-diameter brakes in spite of higher driving speeds. Lining manufacturers have found it necessary to furnish materials having a greater wear factor and less fade at high temperatures. Improvements have also been made to keep dimensional changes at a minimum under heat and pressure.

Centrifuse drums are now made with lighter metal in the drum backs, which has been compensated for by increasing the lateral rigidity by convolutions. This also provides radial flexibility to encourage parallel expansion of the drum under heat and pressure from the brake-shoes. The back corner has been eliminated and 12 rivets have been added to the 12 projection welds used in 1932. This construction gives a more rigid joint with better heat conductivity, and the radiating surface of the ring is increased by exposing the back corner. These drums are used on the Auburn, Buick, Chrysler, Dodge, De Soto, Federal truck, Franklin, Nash, Plymouth, Packard, Reo and Reo truck.

All Cadillac models employ a booster, with a consequent shortening of the brake pedal on the eight and the La Salle. Hudson eight and the Chrysler Imperial Custom have also joined the ranks with this unit. Auburn now uses hydraulic brakes and adds a vacuum booster in conjunction therewith on the 12's. A dash control, similar to that on the Stutz, allows a varying degree of boosting for different road conditions. The hand brake operates on the rear wheels through the same shoes of the hydraulic system. Oldsmobile uses diagonal braking, with brake rods paralleling the X-cross-member channels, and cable connection from the frame to the wheels, as shown in Fig. 17. Last year the Terraplane utilized diagonal braking but has not continued it. A coil spring surrounds each Cadillac drum on all models to give additional cooling surface and absorb any noise produced by vibrations in the drum. Pierce-Arrow is using the Stewart-Warner servo system, with a single cross-shaft on the front axle and one on the rear axle, with a single-cable connection forward and to the rear from the unit. A treadle, not unlike the accelerator pedal, is used instead of the conventional brake-pedal, owing to the small movement and the light pressure required. Rigidly anchored two-shoe brakes are used with this system. The front-wheel braking effort is decreased in proportion to the turning angle, as a result of the cam-surface development, the cam being in line with a knuckle-pin axis.

The Plymouth hydraulic operating cylinders have a $\frac{1}{8}$-in. larger diameter in front than at the rear, to increase the braking effort on the front wheels. The separate parking brake-shoe has been eliminated from the Chevrolet, the hand brake being interconnected with the foot-brake system through a sliding link connection. Steeldraulic brakes continue on DeVaux, Continental, Auburn, Rockne and Hupp.

Changes in Front-Axle Practice

For the Franklin company to discontinue use of the tubular front axle seems strange. It has changed over to an I-section drop-forged center on the 12 and the Olympic. The Dodge and Plymouth, on the other hand, have a tubular axle center with welded-on spring-pads. Thrust bearings are of the ball type and Oilite bushings are used for the pins. On the Chrysler eight the knuckle-pin bearings are protected by an improved type of seal. With the adoption of low-pressure tires, Dodge maintains the camber between 0 and 1 deg., with $\frac{1}{4}$ deg. preferred, whereas it was formerly maintained between $\frac{1}{2}$ and 2 deg., 1 deg. being preferred. The caster remains at $\frac{1}{2}$ to 2 deg. and the toe-in is unchanged, being 1/32 in. at each side. The knuckle-pin inclination has been increased. The Terraplanes have a 3-deg. caster and 2-deg. camber, while the Hudsons have a 1-deg. caster and camber. All have a $\frac{1}{8}$-in. toe-in and 7-deg. knuckle-pin inclination.

The Continental-four axle has a radius rod at each side running to the frame. The anchorage at the left side is coincident with the normal position of the steering-gear ball-end.

In the Pierce-Arrow axle a round section extends between the spring seats and the knuckles. The transverse brake-shaft is located within the rear space of the I-beam center

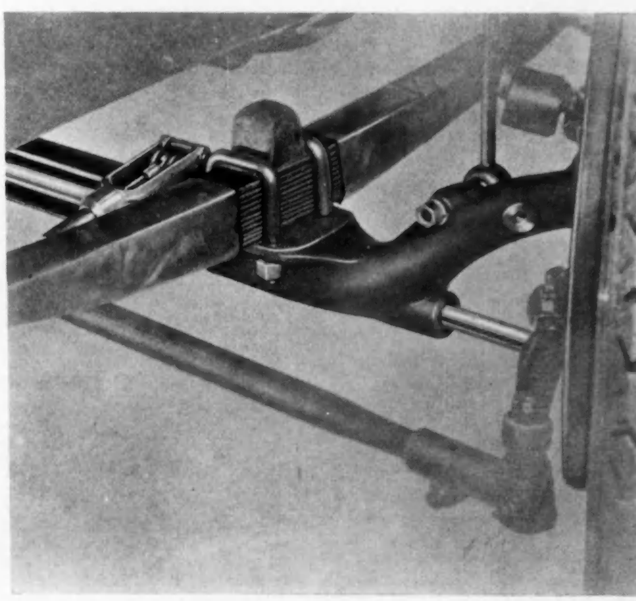


Fig. 18—Pierce-Arrow Front Axle with Cross Brake-Shaft

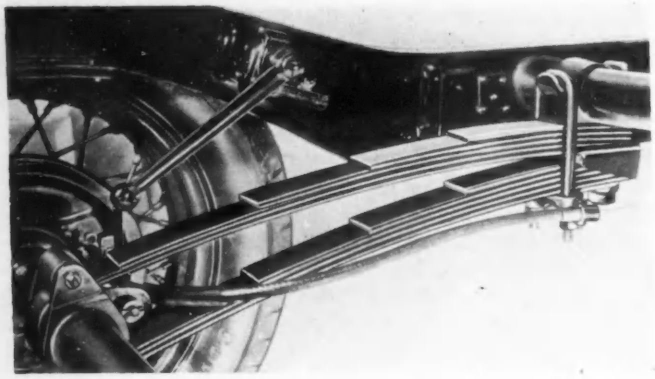


Fig. 19—Continental-Four with Double Cantilever Rear Springs

section, which is offset slightly forward to accommodate it. A round portion, as shown in Fig. 18, supports the shaft midway between the spring seat and the brake cover-plate. All Studebaker models except the 135-in. wheelbase, the Hudson Super-Six and the Willys four and six, are equipped with tie-rods provided with rubber and requiring no lubrication.

The Federal-Mogul Corp. has introduced the Wyromatic compensator, which provides a constant amount of preloading of the bearing and takes up any clearance necessary for expansion or contraction. An adjustment can be held within 0.00025-in. It is applicable to front-axle spindle bearings or rear-axle pinion and worm shafts.

Wheelbases Not Much Altered

On the whole, few changes have been made in wheelbase, probably because of realization of traffic and parking congestion. However, we find the new Buicks increased by 4 to 9 in. and the Chevrolet by 1 7/16 in., while that of the Plymouth has been decreased by 5 in., which was made possible by better engine-space utilization and placing the radiator ahead of the front axle. The Willys four has a wheelbase of 100 in., with front and rear treads 50 and 51 in. respectively. It has a left turning radius of 18 ft. and a right turning radius of 16¾ ft. The wheelbase of the Terraplane six is 106 in. and the tread 56 in. The Continental four has a 101½-in. wheelbase and similar tread.

Steel Wheels and Small Rims in Favor

A recent development by Motor Wheel is that of an artillery-type steel-spoke wheel. Small tire diameters and the drop-center rim have reduced spoke lengths to such an extent that the wheel can be drawn from narrow strip steel, leaving very little metal for waste. The center flange is designed so that the wheel can be mounted interchangeably on the same hub as wire or demountable wood wheels. The steel wheel is lighter than the wire wheels and compares favorably in strength on static, impact and fatigue tests with other wheel types. Buicks are furnished with artillery-type wheels of stamped-steel construction, the one-piece stamping having a cover plate over the back of the spokes. Wire wheels are optional. Studebaker cars continue to be equipped with metal artillery wheels, which can be furnished either chromium-plated or painted, with wire wheels optional. The Oldsmobile has a special steel wheel incorporating 18 spokes.

The 17-in. rim dominates the field, with Dodge and the Terraplane eight using 16-in. rims. Makers of several medium-heavy cars are considering 15 and 16-in. for 1933-34.

The Tire Situation

Last spring's and summer's change-over program for super-balloon tires proved to be a disappointment because of unsatisfactory tire wear owing to the pressures recommended being altogether too low. Proposed sections ranged from 6.00 to 9.75, with pressures of 16 to 24 lb. per sq. in. Lower-pressure tires must be a compromise between this extreme and present balloons and pressures ranging from 25 to 30 lb. Dodge and the Terraplane eight are the only cars in full production on a 6.00x16 four-ply tire, although this same type is optional with Graham, the small Nash and some Chrysler units. While appearance, traction and skidding resistance have been improved with these tires, they accentuate the problem of steering, tramp and shimmy.

Goodyear has introduced a rubber-covered, standard metal-valve inside which forms an integral part of the tube to prevent its tearing in case of puncture, the rubber-covered valve slipping back into the shoe. Lock-nuts are eliminated. The United States Rubber Co. has introduced a corrugated tube to allow escape of the entrapped air between the tube and the shoe through the valve hole.

Balloon tires are used on trucks and buses almost to the exclusion of other types. The White city bus uses 12.00x20 front tires and 9.00x24 dual rear tires, with provision for oversizing to 12.75 and 9.75, respectively. Rail-car tires have proved to be an interesting development. The Goodyear tire has a 2400-lb. carrying capacity, with inflation pressures of 105 to 120 lb. per sq. in. A three-segment safety ring is used on the rim inside the shoe and surrounded by a special tube to prevent too great a drop of the wheel in case of puncture. The cast rim is continued with an inside flange for rail guidance.

The farm-tractor tire is another development which probably will revolutionize the tractor industry. Goodyear builds a small-hub-diameter tire similar to its airwheel. Firestone, however, has based its design on a 24-in. rim which, with the low pressure and large section-diameter, is claimed to provide greater stability. It uses only one-half the power required with steel lugs, with resultant fuel economy.

Improved Shackling of Suspension Springs

With the introduction of semi-elliptic springs on the Franklin 12 and the Olympic, this type of spring is now virtually universal. Fafnir ball-bearing shackles are used on the 12, while the Olympic utilizes the Tryon sleeve-adjusting unit. The latter is used also on the Willys four and six. Studebaker and Pierce-Arrow are using the Fafnir shackle on all models. Rockne, Pontiac and Oldsmobile use the threaded type. The front ends are attached to the frame through rubber bushings. Graham and the Hupp eight use rubber, front and rear. The Hupp-six shackle is a combined rubber and threaded-bolt type. The Chrysler Imperial-eight springs are rubber-bushed at each end, with the addition of bronze bushings at the rear end of each spring. Auburn uses a threaded-type bushing and bolt for the fixed end of the front and rear springs.

The U-shackle introduced by Plymouth last spring is retained and is also used on the Dodge, De Soto, Chrysler six and Royal eight, and the Terraplane eight. There are two hardened sleeves threaded inside and out and a U-shaped link, also threaded. The sleeves are screwed into the eyes of the spring and the frame brackets, and at the same time the legs of the U are threaded into the sleeves. The U-

shackles are located at the rear of the springs, while the front ends are fixed in rubber-bushed supports. With the threaded type of shackle, Chrysler has changed the recommended period for lubrication from 500 to 2000 miles. Spring-type kick-shackles replace last year's rubber design on the Chrysler Imperial and the Imperial Custom eights.

No kick shackles are used on Plymouth and Dodge because of the new steering layout, and the fixed spring-eye is forward. The front springs are located outside of the frame so as to lower its height. All cars in the Chrysler group now use the Oilite spring inserts. All Hudson models retain the splayed rear springs.

Practice with Regard to Springs

Pontiac and Oldsmobile have the axle insulated from the springs by rubber. Spring covers are used on the various General Motors cars other than Chevrolet, which has a curled leaf-end incorporated in the spring, similar to last year's Buick. Correct fit of the rear spring in the front hanger-bracket is assured by providing a replaceable thrust washer between the spring and the bracket. This obviates the former bending-in of the bracket to take up wear. On the White city bus, the semi-elliptic springs are interchangeable, front and rear. The threaded type of shackle is also used.

The Continental four has a double cantilever rear spring, depicted in Fig. 19, anchored to the tubular cross-member. The rear fastening to the axle is by means of threaded bushings. The springs measure 26 x 2 in. A transverse front spring is used, centrally anchored to the front cross-member and fixed at the left eye to the front axle. A U-shackle goes to the right eye.

Frames Designed for Front-End Rigidity

Front-end rigidity is the chief aim of the new frame designs. In the Plymouth and Dodge the front cross-member extends diagonally forward at each side and continues inside the side rail. The forward continuation of the X-frame members, also within the side rail, extends diagonally inward to meet the front cross-member and form a box section therewith over the central portion. This construction is illustrated in the Dodge chassis in Fig. 20. The springs are attached to a stamping below the front end, which is offset outward to line up with the outboard spring. The bracket also acts as a fender anchorage by clamping the fender apron between the bracket and the bumper-clip support. New adherents of the X-cross-member construction are the Buick, Oldsmobile, Willys and Franklin Olympic.

In the Terraplane, the bottom pan of the body has 19 points of attachment to the frame, including several points on the X-cross-member, thus tying the frame structure and the body together to form a comparatively rigid unit. On this basis, an unusually light frame-section can be used. The front seat also bolts through the body pan of the X-cross-member. The only openings in the pan are for the rear-axle center clearance and the battery box. The K-cross-member at the front of box section consists of a straight transverse channel, to the rear of which is secured another channel running diagonally back at each side and incorporating the front engine-supports. Hudson and Graham have similar K-form front cross-members, the latter being shown in Fig. 21. Graham continues the banjo construction at the rear axle and has a Y-termination at each side of the rear engine-support cross-member.

In the Auburn X + A frame, the X-cross-member channels are continued diagonally forward, immediately after being secured to the side rails, and terminate at the center of the front cross-member, as seen in Fig. 22. It might be considered as a modified K-construction with an extremely long diagonal, continuing into the X portion. A double-flanged, second cross-member is located slightly to the rear of the front one and is secured to the top of the A-members. A channel anchored within the ends of the second cross-member goes below the A-members. From the rear of the X-cross-member, Auburn runs a channel liner to the rear end of the frame, with vertical offsets of the flanges at the kick-up to strengthen same. Auburn claims 200 per cent more rigidity over the conventional X-type frame, with an increase in weight of only 11 per cent.

Oldsmobile and Buick extend the frame back beyond the rear shackle for adequate support of the rear apron and body panel respectively. The Hupp torsional stabilizer for the front end of the frame is now also incorporated in the six-cylinder model.

The Hudson company utilizes welding in its frame construction. The Chevrolet company provides a small kick-up at the front and stiffens the rear kick-up portion of the side rails by depressing a panel therein. A combination sub-frame channel and engine support is located at the left side and extends back to the transmission cross-member, a wide gusset-plate and engine support being located at the right. A cross-member extends between the two. The rear Chevrolet cross-member is considerably raised at the center and webbed for the tire carrier. The Continental four has

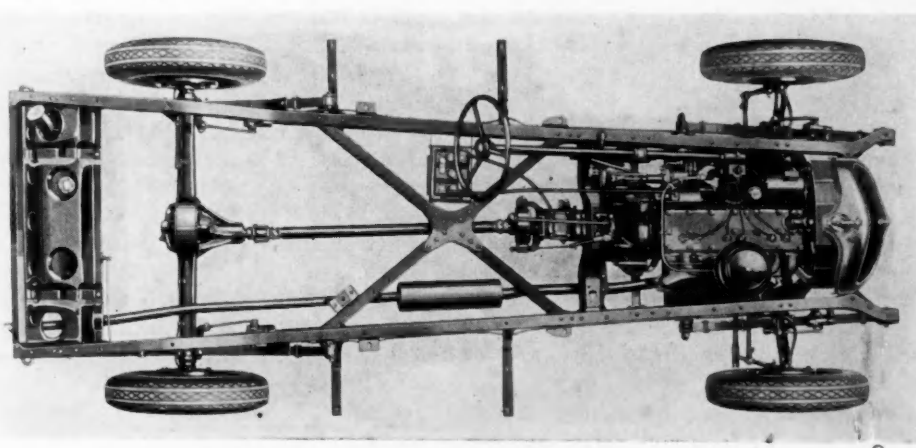


FIG. 20—DODGE CHASSIS WITH OFFSET FRAME AT THE FRONT

a depressed panel in the side rails from the rear of the engine to the kick-up.

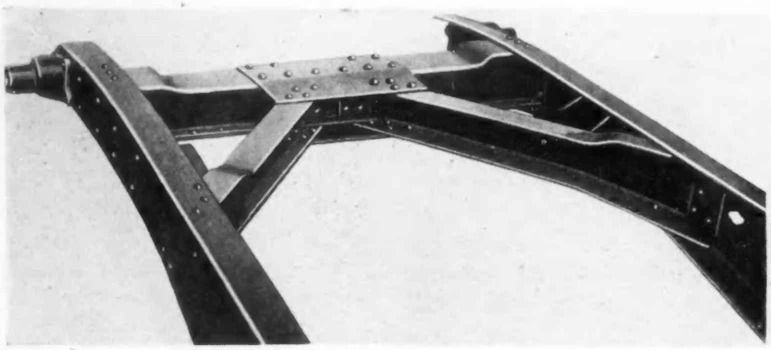


Fig. 21—Graham K-Type Front Cross-Member

Control Has Been Simplified

Simplification of control is a prominent feature of the new cars, as is indicated by the use of an automatic choke, fast idle, hot-spot heating and the accelerator-starter hook-up. In the commercial field, power steering and clutch operation and ease of gearshifting reduce driving fatigue to the lowest point, making for greater safety.

There is a tendency on passenger-cars to produce a faster steering action. Many cars of the heavier type have been using ratios as high as 20:1. Under such conditions and with car speeds going up, the driver will unconsciously oversteer, with the result that there is some wandering action before straightening out. Steering ratios approximating 18:1 are now used to correct such action. The same is true with middle-priced sixes and eights, in which ratios of 17 and 18:1 are being replaced by 15 or 16:1.

To secure the easy-steering effects to which the public has been educated, these changes require the very highest over-all efficiency of the steering mechanism. The gear must also withstand considerable mileage of hard driving without the need of frequent service adjustments. The greater use of antifriction bearings eliminates front-end friction but accentuates the need of accurate front-end geometry. There are experimental cars on the road with needle bearings in the knuckle-pins and a ball-bearing tie-rod and drag-link. The Baker ball-bearing rod and link has been well received in the replacement field and will shortly be used in original equipment. The Studebaker drag-link has a magazine-type oiling system requiring attention only at 5000-mile intervals. The Gemmer Mfg. Co. is using flexible, small-diameter steel roller bearings which extend the entire length of the cross-shaft, taking the place of the former bronze journal bushings.

The Baker Wheel & Rim Co. has developed a steering stabilizer consisting essentially of a hydraulic shock-absorber built into the steering-gear housing and acting on the cross-shaft. About 5 deg. each side of the central position is a restricted range to absorb road shocks. Beyond that the gear is free.

Plymouth, Chevrolet and Pontiac have a 14:1 ratio and utilize taper roller bearings to support the worm-shaft. The Willys four and six have ratios of 12:1 and 13:1 respectively. Plymouth uses Oilite bushings for the cross-shaft. On the Plymouth and Dodge a transverse drag-link is used to give freedom from road shock and to secure better steering geometry. This construction also allows greater inclination of the steering column. The Buick-50 series now has a worm-and-roller type of gear similiar to that of the larger series. The steering column and bracket on the Auburn 12's are finished in chromium.

Mounting of the gearshift lever on a frame cross-member is used by Plymouth, Dodge, De Soto and Willys and prevents any transmission of vibration from the powerplant. This construction surely will be used to a larger extent, as has been the case with the frame-mounted pedals. Graham now utilizes the latter construction, and the clutch throw-out shaft between the pedal and clutch housing consists of a tubular member with a ball universal and slip joint at each end. The Chevrolet pedals now pivot on a shaft anchored to the frame web and are supported by a twisted bracket of flat stock surrounding the shaft between the pedals and serving as a stop for both. Buick and Cadillac mount the brake pedal on roller bearings. In the Chrysler-group cars the pedals and master cylinder are built around the intermediate cross-member.

Both the White city bus and the Mack street-car type have hyraulic boosters and are the forerunners of power steering, which is certain to come in the heavier commercial vehicles. An interesting control mechanism is incorporated in the Studebaker door-to-door delivery wagon with the Edwards Monotrol. The Bendix automatic clutch and booster-brake units are used. By moving a single control lever downward, the engine is accelerated and the clutch engaged. When in a horizontal position, the throttle is closed and the clutch disengaged, whereupon the vehicle coasts. Upward motion of the lever appiles the brakes through the booster.

Bumpers, Shock-Absorbers and Head-Lamps

A distinctive new-type bumper is that on the Cadillacs. The central portion consists of three round bars connecting the single-bar ends, which taper in height toward the middle. De Soto is using a convex bar which dips down and back in the center and diminishes in height toward each end. The Buick company attaches a metal deflector to the inside of the rear-bumper bar to prevent gravel being thrown up on the back of the body. The single-wide-bar bumper now dominates the field. Graham introduces a new style with two bumper halves, exposing and following the line of the lower portion of the radiator grille. Each half slopes down toward the center and has oppositely curved ends. Auburn has a propeller-type bumper, dropped and narrowed in the center, with paired-off ends.

The Buick ride-control type of shock-absorber has been replaced with the new Delco inertia control, which is also used on the Chrysler eights. A weighted valve within each shock-absorber is held open by an extremely sensitive spring. As long as the valve stands open, the shock-absorber is free. An upward thrust of the car body instantly closes the inertia control-valve and the resistance of the shock-absorber comes into effect to oppose a rebound of the car springs. Should a wheel drop into a rut, the axle will not pull the frame down, since the inertia valve is not affected. Studebaker continues with the automatic ride-control, in which the effective orifice varies with the velocity of the discharge therethrough. A variation of less than 8 per cent over a temperature range of 100 deg. is claimed for the Monroe shock-absorber. The piston has a thermal expansion three

times as great as that of the cylinder in which it works. There is also a pressure-relief valve inside the piston. Monroe takes a graph of every instrument to check its operation on both the recoil and compression strokes.

Non-Glare Headlighting Arrangement

In the Pierce-Arrow lens and reflector design, the light rays from the right head-lamp are deflected to the left side of the road and those from the left head-lamp to the right. The spread of light, with this cross-beam illumination, is such that the road is better lighted both for width and distance than with the conventional lamp. For passing cars on the road, the light-switch can be moved to a position that provides for the left side of the road being illuminated with a dim light by using the depressed beam of the right head-lamp, while the right side is given the full advantage of a bright light. This eliminates glare, and the driver has complete illumination of his side of the road. In addition, both head-lamps can be dimmed by using the depressed beams.

Pierce-Arrow has placed a companion tail-light on the right rear fender. Chrysler, Buick and Graham utilize the same type of multi-beam headlighting. There are a number of new users of the foot-operated switch to control the upper and lower beams.

Tail-lamps are generally of the type with the upper portion forming the tail-light, with the license-plate suspended above, and the lower portion forming the stop-light. Reflex prisms are also universal. To prevent waste of current, the Chevrolet stop-light is connected to the ignition circuit so that it is operable only when the ignition switch is on. The lighting switch is operated by both pedal and hand lever because of the new brake-rigging layout. Auburn provides a two-way switch on the dash, which allows the operator to flood-light the front compartment or to light the instruments indirectly.

Speedometers, Instrument Panels and Wipers

The principal development in speedometers has been in the elimination of the drum type and the use of a pointer instead. Large-diameter dials, big figures and pronounced graduation marks tend to make the instrument more legible. This is exemplified in the Cadillac, Olds and De Soto. In the latter the oil, gasoline and water-temperature indicators and the ammeter are arranged compactly, each in one corner about the speedometer, and all are under one glass. The instrument panel itself is of translucent glass, giving an entirely new effect when lighted. Graham also utilizes translucent glass and all instruments are compactly grouped within the 6¼-in.-diameter speedometer dial, a pleasing layout. A chromium-plated speedometer needle is used and the speedometer background is white. The Pontiac dials are white on black for greater contrast Some of the polished beads heretofore used in panels have been eliminated and simpler face-plates have been substituted or in some cases entirely abandoned.

In the Olds panel the complete instrument installation is combined in two large round-faced clusters having crowned-glass crystals, which type of glass is practically universal on all instruments. The Buick instrument board incorporates an ash receptacle and detachable cigar lighter in the center, with the instruments at the left and a package compartment at the right. The starter button is located at the extreme left. Antique-bronze finish is used for the panels. On the Marmon 16 an opalescent finish is used. The electric gasoline gage has outnumbered all other types. The Terraplane eight has a pull-out map light on the instrument panel.

Wider use of the A. C. vacuum pump, either alone or in combination with the engine-driven gasoline pump, to operate the windshield wiper and give uniform wiping at all speeds, is evident and is standard on the Buick, Chrysler, Cadillac, Lincoln, Nash, Packard and Studebaker.

Closed Cars Wired for Radio

The elbow type of horn under the head-lamp is very popular and continues in dual form except in the low-priced group. All closed cars are now wired for radio, and the American Bosch Magmotor is a recent development to eliminate the use of B batteries. In the Chevrolet, Plymouth, Dodge and De Soto the front license-tag bracket is attached to the front spring horn by the same bolt and clamp which attach the bumper. Rear tire-covers are now of the closed-back type, cleaning up the otherwise exposed portion of the spare wheel.

Various new designs eliminate the use of clamps over the tire in the fender well. Buick applies pressure at the hub by means of a knurled nut even with the top of the tire and an intervening compression member. In the Oldsmobile and De Soto, transverse rigidity of the wheel is obtained by a combination lock-tumbler and nut which holds the hub against the bracket through the intermediary of a slotted disc, all of which is covered by the hub cap. Pressure is exerted on the inside rim flange by a stamped bar held down by a wing-nut.

Sheet Metal Becoming Graceful

Great effort has been expended this year in the design of the sheet-metal parts, which are necessarily considered in the body ensemble. Gracefully curved surfaces that blend into one another without violent breaks subconsciously indicate speed and also give eye appeal by the hiding of chassis parts and details that otherwise would break up the continuity of surface and line.

Fenders are brought down considerably lower ahead of the

Fig. 22—Auburn A-Extension of the X-Type Cross-Member

front wheels. Very deep crowns are used and the apron is losing its identity through the merging of the two into one curved surface The radiator apron also has been entirely changed from its former straight surface to a curved member continuing the curvature of the fenders and the lower portion of the radiator. In the case of De Soto, the front fender is made in one piece with half the radiator apron, the joint between the two units occurring at the center. In the Plymouth and Dodge cars, the offset front-frame construction offers great stability to the front fenders so that it is possible to mount the lamps thereon without a cross brace. The present sweeping surfaces of the fenders entirely hide the chassis structure beneath.

The Terraplane and the Chrysler-group cars have a high hood-sill line, considerably above the top of the frame where it has heretofore been located. This eliminates the disagreeable deep V between the fender and the hood. Besides the improved appearance, the stamping operations are facilitated and the amount of necessary material reduced.

Fender Valances Improve Appearance

Adoption of the fender valance, introduced last year by Graham, shows another distinct effort to conceal the chassis and enhance the car appearance. The former ugly and often dirty fender-well bottom is also hidden. Considerable road splash on the body is prevented by this added apron. This is particularly true in the case of cars in the General Motors group, in which a horizontal in-turned flange not only reinforces the structure but extends inwardly sufficiently far to catch the splash. Common practice is to support the forward valance by a channel-shaped bracket, whereas the rear-fender valance uses the ordinary type of fender iron.

A particularly smart effect is obtained by Buick in the placing of a cap piece between the front fender and the radiator apron, enclosing the bumper support and continuing the curvature of the two aprons. The raised bead along the edge of the fenders is carried around and through the cap piece, further enhancing the continuity of line. In the General Motors group, the lower edge of the valance of the front and rear fenders is curved, aiding in the elimination of straight lines. Cadillac, however, is an exception in that the lower edges are fairly straight. Pontiac breaks up the flat surface of the valance by introducing two raised beads into this surface, blending into the curved bead back of the wheel opening.

Pierce-Arrow and Studebaker have the low sweep forward in the front fenders and place a large radius in the corner formed by the wheel opening and the lower edge of the valance, which is restricted to the front fenders. The General Motors group have a very small radius at this point, with the idea of greater concealing ability. The Pierce-Arrow head-lamp is blended into the fender so that the lamp-enclosing portion is a harmonious continuity of the fender-crown curve. The Olds front-fender crown and the running-board extension meet without any intervening radius, giving the odd fender styling seen in Fig. 23.

Head-on View More Pleasing

The combined fender and radiator bracket introduced last year by Chevrolet, having a resilient center-mounting on the front cross-member together with a radiator liner and lamp cross-rod tied in to the fenders, is now used by the rest of the General Motors group, preventing frame movement being conveyed to these parts.

With the rising hood-sill line and the use of the fender valance, it does not take much imagination to see that in the not distant future the front fenders and hood will be combined into one surface of blending curves. This observation is further accentuated by standing in front of the Plymouth to see wherein the whole front end, radiator and fenders can be combined easily and gracefully.

At the back end of the car, the gasoline tank and chassis are completely hidden from view by the rear apron, which in most cases follows the back flare of the fenders. Rubber grommets are used to close all openings regardless of shape. Buick has eliminated the rear apron by combining this portion in the body, but in the rest of the General Motors group the apron continues the concave rear body-panel with similar effect. Cadillac, however, is an exception and continues with the orthodox convex panel and the rear apron raised above the fender line.

The Cadillac hood sides are provided with two rows of three horizontal doors, each having a long vane-like handle, to accentuate length. The Oldsmobile hood has torpedo-shaped doors, as seen in Fig. 23. All cars of the Chrysler group now carry the hood very close to the base of the windshield, curving forward at the center to leave room for a cowl ventilator. Hupp also carries the hood to the windshield and gives clearance for the ventilator. The Buick, Hupp, Pierce-Arrow and Chevrolet have slanting hood doors to be in keeping with the sloping radiator and the now almost universal sloping rear hood-edge. Pontiac maintains four large louvers at the back. A single center handle is employed on the Buick and Oldsmobile for locking the hood to the dash and radiator, so as to utilize the hood structure to aid front-end stability. The Stutz has thermostatically controlled hood-doors, each side being independently controlled. Each hood top is curved at its forward, center corner on the Buick and Plymouth, giving a pleasing lap of the hood on the radiator shell, a feature introduced last year by Graham. The rear, bottom corner of the Buick hood is curved, with a resultant pleasing effect that is impossible with a sharp corner. Hupp uses an exceptionally big radius at this point. Buick supports the engine pans independently of the crankcase so as to suppress noises.

Body Streamlining Coming by Steps

Radical body changes are not acceptable to the public, hence the streamlining effort must be accomplished in gradual steps. Present changes are not extreme, but a decided foundation is being laid for future and more unconventional design. The body and sheet-metal work both have such flowing surfaces and lines that it can really be said that they now merge into a harmonious whole without one's being aware of the chassis beneath them. In general, larger interiors are provided. The outstanding feature of the body exterior is the rear treatment, best exemplified by the Buick, in which there is no break in the rear body-panel, which covers the gas tank, with only a filler cap inconspicuously protruding. The panel flares back in conformity with the fender sweep, and the continuous effect obtained by the elimination of a separate apron is most pleasing and gives instinctively the impression of lessened air resistance.

Buick is able to continue the rear panel over the back because of the present low bottom line of the body, which meets the running-boards at the sides, with the door opening close to them, accentuating lowness. Chevrolet and Pontiac doors extend half way to the running-board.

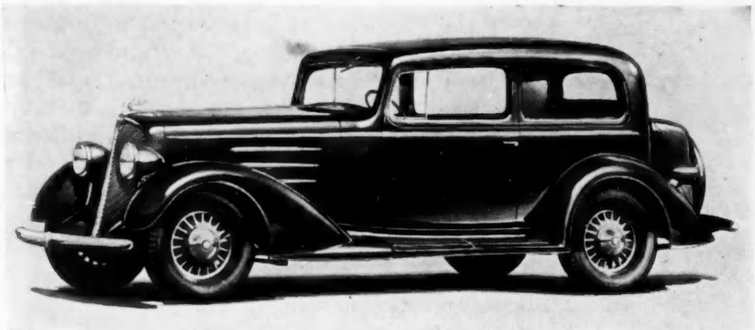


Fig. 23—Oldsmobile-Eight Five-Passenger Touring Coupé with New Radiator, Hood, Belt Molding, Fender and Wheel Design

There is a general trend by many toward the concave rear panel. Rounded, built-in trunks at the back of the body are increasingly popular and, to the uninitiated, slightly soften the concave rear deck. All Oldsmobiles have such trunks on sedan and coupé models. With the Buick doors considerably below floor level, a rubber sealing strip is used between the door and the upper portion of the sill. Cadillac uses a rubber dam on the top of the doors, which also acts as a weatherstrip. One-piece garnish moldings are used more than formerly. The Auburn-12 moldings have a two-tone walnut finish. Rear-quarter windows of D-shape are being made larger. Front doors in the Chrysler group, Hupp, Auburn, Studebaker and Pierce-Arrow, all have a sloping forward edge, giving greater foot room for entering or leaving. Auburn places dovetails at the top and side of both front doors to check rattles. A tubular-strut bracing of the cowl runs from the door pillars to the center of the dash, where it is welded in position. Struts also run from the front of the dash to the side rails of the frame.

Ventilation and Windshield Treatment

Among body features, the Fisher No-Draft ventilation is the outstanding development. The front windows and the rear-quarter windows in all sedans have a separate forward section which pivots at top and bottom and can be swung outwardly to any desired degree, inducing a vacuum within the body and thereby ejecting the stale air. A small amount of pure air enters the forward opening. The deflector is moved by means of a handle operating a worm mechanism. The rear portion of the front-door windows can be raised or lowered, and the sloping forward edge is provided with a channel that locks the deflector in position when shut. The windshield is now permanently fixed in its frame, the VV windshield having been eliminated. A cowl ventilator is used instead and is fitted with a fine-mesh screen. In the Cadillac and LaSalle a single top-cowl, rain-proof ventilator is used. The opening is provided with baffles and a drain, giving ventilation in inclement weather and preventing steaming of the windows.

Windshield inclination on the Buick has been changed from 10 deg. to 18 deg., giving a more rakish appearance and reducing wind resistance. The Auburn has a slanting V-type, air-unit windshield. The Chevrolet, Pontiac and Buick are provided with an inside visor that can be swung around to give protection to the left side. A stationary bracket is located at the left and a removable pin at the right can be inserted in a hole in the header or side. The Cadillac and some of the Chrysler units have a swinging arm with a ball joint at its end where it supports the visor.

Windshield wipers are now universally mounted in the header bar, out of sight. Stewart-Warner have introduced an engine-driven windshield cleaner, operating through a flexible shaft and a clutch control. Windshield defrosters of the electrical radiant-heater type are being made available as optional equipment on numerous cars.

Body Insulation and Door Treatment

Silencing and heat insulation of body and door panels continues, with linings of numerous types cemented thereto. Jute-felt and asphaltum board are popular. Johns-Manville have introduced a Silento felt approximately 1/16 in. thick, which is unaffected by moisture. A special cement is furnished and, with the felt, can withstand a temperature of 300 deg. fahr. without disintegrating or slipping off the panel. Dash-boards also are continued with noise and heat insulating materials of like type. For further silencing, metal clips to hold the tools in position and prevent their rattling are provided in Buick tool-boxes. The Oldsmobile window panels have a two-step reveal. There are two narrow, adjacent belt moldings that overlap at either end, extending back to the rear-quarter panel and carried forward to the front of the hood.

The Fisher bodies have a safety door-lock operated by a small button on the window molding, the position of which indicates whether or not the door is locked. The lock frees the handle when locked from the inside and a pin shears off should the locking handle be forced beyond its free limit, saving the lock from destruction. Some of the Chrysler units have a front right door handle that is entirely free after the door is locked. Window curtains operating through slots are furnished in the Buick, the rollers being concealed.

Running-Boards Have Had Attention

The Chevrolet running-board and apron are stamped in a single piece. The board is curved gradually down toward its outer edge and has a deep-channel rib running along the middle. The top of the running-board is covered entirely by a soft black-rubber mat vulcanized on a steel plate to which 14 T-shaped clips are permanently attached. These engage depressed slots in the running-board, the surrounding metal having a cam surface which pulls the mat down tightly when the clips are twisted into place. The Oldsmobile has a similar mat. A rubberized-fabric gravel deflector is attached below the rear end of the Buick running-board. The Terraplane and the General Motors group continue in the front end of the running-board the long sweeping line initiated by the front fender. Graham places a chromium-plated strip along the running-board, starting at the bottom of the front fender and following for a short distance the front upward curve of the rear fender.

Whipcord trim is standard in the Oldsmobile touring coupé, sedan and sport coupé. All other models have mohair as standard. Cushions are trimmed pillow style, the rear cushions being divided into three panels held fast by large buttons. The Auburn-eight upholstery is of the pleated, button type in broadcloth. The 12's are done in pleated motif and edged in braid. Zipper-type pockets are used. The Dodge upholstery has alternate wide and narrow pleats. Buick has cloth, plush or whipcord upholstery available in the closed models. Fabrics are applied with the seating divisions out-

lined in tailored trimming. Deep-velvet-pile carpets are provided in the rear of all sedans and five-passenger coupés. The Buick has carpet-covered footrests and chromium-plated robe rails. Auburn provides a panel-type footrest which folds into the back of the front seat, providing additional luggage space in the rear compartment.

New Developments in Commercial Vehicles

Legislation restricting over-all length of commercial vehicles no doubt will give an impetus to the tendency to place the cab over the engine, with resultant heavier front-axle loading. Undoubtedly the White horizontal engine now used in the city coach will be utilized also to this end.

Freight transportation by road tractors and trailers has grown considerably in the last year and has reached a point where a trailer or a semi-trailer is passed along in interstate commerce to be hauled by different operators, as is the railroad freight-car. Standardization of coupling parts is essential, and the program of fifth-wheel standardization must go forward more rapidly.

As a trailer equipped with B-K vacuum brakes is sometimes passed along to a second operator whose tractor is equipped with compressed air, the Bragg-Kliesrath Corp. has developed a method for meeting this condition. A vacuum line is added to the tractor, and the standard relay-valve on the trailer is provided with a piston actuated by a small quantity of compressed air when the tractor brakes are applied. A lever on the relay valve can be shifted to one of two positions, depending on whether the trailer is to be operated with a tractor having compressed air or a complete vacuum system.

Considerable activity has developed in the field of door-to-door delivery trucks, as evidenced by the Continental-Divco, Ford, Chevrolet, White-Indiana, International Harvester, Studebaker, Stutz, DeKalb, and the Walker and Ward electrics. The Twin Coach Co. has developed a front-drive vehicle with the entire powerplant ahead of the front axle. It has also evolved a new type of garbage-removal truck having a collapsible rubber-sealed ramp over the rear axle and normally resting on the frame kick-up but straightening out to form a level floor when dumping. Considerable effort has been expended in the building of refrigerator bodies for dry-ice and mechanical refrigerators. Two-ply stainless steel has found its way into numerous automotive applications, the latest being tanks for milk trucks. These aim to compete with glass-lined tanks.

Notable Rail-Car Construction

The Budd and Twin Coach rail-cars deserve mention in view of the overlapping of the automotive and the railroad fields. Through the Edward G. Budd Mfg. Co.'s process of shot-welding, stainless steel has been used throughout the rail-car, including the trucks. Each truck has six pneumatic-tired wheels, and the powerplant and a generator are mounted on one truck and the motor and the driving mechanism on the other.

The Twin Coach Co. has developed a combined rail and highway motorcoach. In front of and behind each of the four rubber-tired wheels is a flanged guide-wheel mounted on a rigging attached to the brake spiders of the regular production job. Raising the guide wheels above the level of the rails and driving off allows operation over the highway. Used as a truck, with or without trailers, this has great possibilities in the field of store-door delivery for the railroads.

From this résumé it will be seen that there has been much activity in the last year in all branches of automotive engineering. It is regretted that the early form-closing date of the S.A.E. JOURNAL prevents mentioning a few car manufacturers who were unable to release information in time.

HOW VERSATILE ENGINEERING MEETS PUBLIC DEMAND

By H. M. CRANE

Irritated by statements of some alleged economists to the effect that, except for changes in the appearance of motor-cars, the automobile industry has stood still for the last five years, the author of this paper, who is affectionately regarded as the dean of automobile engineering in this Country, spoke at meetings of the Philadelphia and Metropolitan Sections of the Society on the many car and engine improvements made in recent years.

Mr. Crane's remarks, as reported stenographically and embodied in this paper, deal chiefly with engines. He points out that extensive highway improvement and the consequent public demand for higher car speed have forced engineers to design more powerful and more versatile engines without increasing the weight.

High-speed engines were of necessity the answer, and these brought the problem of eliminating roughness of operation and preventing transmission of vibration to the chassis. The solution has been found in using a larger number of cylinders of small size and in the flexible suspension of engines of four and six cylinders.

In-line and V-type engines of 4 to 16 cylinders are discussed, and, in answers to questions, the speaker considers horizontal opposed and air-cooled and high-temperature liquid-cooled engines for streamline cars.

The present and probable future trend in car design is also considered.

ABOUT the time that I was asked to speak before the Metropolitan Section, I was also asked to speak before the Philadelphia Section, and I went down to Philadelphia to talk largely because I had been considerably irritated by statements of certain alleged economists to the effect that the automobile industry had stood still for five years except for making occasional changes in the appearance of motor-cars and that automobile users would return to a more rational type of buying in the future; that is, that a man would buy a car only when his old one was worn out.

Until I was waked up by these statements I had not given enough thought to what really had been happening. In the development of the general design of the motor-car during the last five or six years, the automotive engineers were struggling to keep up with entirely normal demands of the motoring public for improvement, not radical or revolutionary design but reasonable improvement of fairly conventional design.

New Cars Satisfy New Conditions

The reason for this demand is that the conditions under which a motor-car is used in this Country today are very different from the conditions existing even five years ago. The combination of a rapid increase in the mileage of good roads with a much more tolerant attitude toward speed, and a better understanding of speed, has resulted in car speeds that are away beyond anything that was foreseen 10 years ago. A car having a top speed today of 60 m.p.h. is not regarded as first class even in the low-priced field. Not very long ago in my recollection a friend of mine used to bet that no car could be brought to him that could make 60 m.p.h. two ways over a measured mile. In its last year of production the American Locomotive Co. was putting out a large car that sold for $6,000, and the maximum speed was 53 or 54 m.p.h. It was enough at that time, but it is no longer sufficient.

Great forward strides have been taken in automobile design and construction in the last few years and a superior type of car can now be bought at one-eighth the sales price of a much less attractive car of 10 years ago.

Today cars must have versatility to an extent that was unheard of a few years ago. Recently, in Wyoming, my car was called upon to operate under widely different temperature conditions at sustained high speed on level ground and in mountain climbing.

Even persons living in remote places are now car-conscious and public demand forces us to advance.

Higher Speed Required New Engine Types

When I was asked to talk on the subject of engines, my impression was that I had recently addressed the Metropolitan Section on that subject and that probably I could add very little to the discussion at this time; but I was surprised to find that that paper[1] was presented in the fall of 1926. The facts given in that paper indicated that the eight-cylinder engine was then the furthest that had been reached in current practice and that many features that are common with us today had not even been considered.

The great increase in motor-car speed that has been demanded by the public has resulted in an entirely new type of engine design and new engineering and, further, an entirely new point of view toward engine mounting. In the old days a car was customarily driven at 30 to 35 m.p.h. An occasional spurt of 55 or even 60 m.p.h. might be made, and, if the engine was noisy or rough, or the car was otherwise uncomfortable at the higher speed, the owner seemed to get a thrill out of it and no objection was made. Now, with the thousands of miles of improved highways that exist, speeds of 50 or 60 m.p.h. continuously for hours at a time

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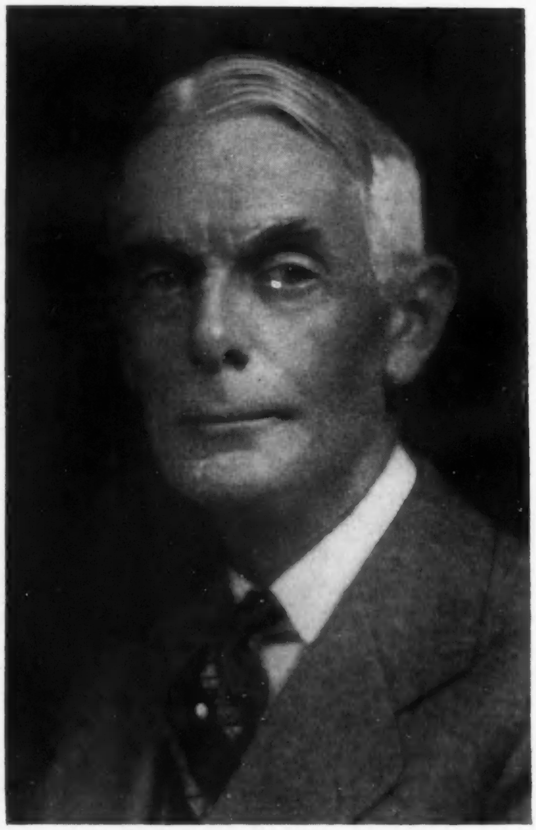
[This paper was presented at a meeting of the Metropolitan Section. The author is a Past-President of the Society and is technical assistant to the president, General Motors Corp., New York City.]

[1] See THE JOURNAL, December, 1926, p. 578.

are quite possible and buyers are no longer satisfied to accept the engine standards of 10 years ago.

This can be readily explained, I think, by Fig. 1, which gives an idea of the great demand for increased versatility in motor-car powerplants. At present, in rating cars as to possible performance, it is customary to rate them on a basis of cubic feet of piston displacement of the engine per ton-mile, and 110 cu. ft. per ton-mile is a good average figure. A number of cars go higher and some rate less. A good average automobile of today will weigh, with a 450-lb. test load, around 16 lb. per cu. in. of displacement.

The different tire sizes shown on the chart are practically representative of the present range of wheel diameters, from the 18 x 7.50 of a big car like a 16-cylinder Cadillac, down to the 17 x 5.25, which is current on Plymouth and smaller cars. The diagonal curved line indicates the actual ratio that, coupled with these tire sizes, will produce the 110 cu. ft. per ton-mile on a car of that weight. As the result of this computation, I find that the engine speed at 60 m.p.h. is 3040 r.p.m.; at 90 m.p.h., 5070, and the intermediate speeds as given in the caption for Fig. 1. Virtually every car now being produced in any standard quantity is capable of a speed of 70 m.p.h. Several cars selling for less than $700 are, or in a short time will be, in existence with speeds reaching up close to 80 m.p.h.; in fact, there will be two or three which will go faster than that with any help from a following wind. That means that, with any normal proportions of car weight, engine size and hill-climbing ability, such cars must have powerplants capable of functioning at more than 4000 r.p.m. without undue distress.



H. M. Crane

Car top speeds probably will not go much higher than they now are, at least for some time, but sustained high speeds will increase. These speeds will be necessary and demanded.

When the Pontiac car was designed not very long ago, the engine was designed to run at a maximum speed of 2500 to 3000 r.p.m. and it was limited to a maximum car speed of 53 or 54 m.p.h. The 1933 Pontiac, which has a straight-eight engine, will have a maximum speed of 76 or 77 m.p.h. and an engine speed close to 4000 r.p.m. at this car speed.

Anyone who has had experience with building gasoline powerplants knows that, to produce an engine that will be reasonably smooth and noiseless at 3000 r.p.m. is quite a trick. Such an engine is now needed at even 60 m.p.h., and at 50 m.p.h. the engine speed is on the order of 2500 to 2600 r.p.m.; and that is a common cruising speed for almost every class of car.

In the paper that I presented six years ago I clearly indicated that there was an increasing advantage in using more and smaller cylinders in arriving at results of this kind. The course of the industry has followed that conclusion, which was an inevitable result of a mathematical consideration, and today we have powerplants ranging from the 16-cylinder Cadillac, which is the outstanding powerplant that shows the way to this type of smoother-running engine, down through a number of 12-cylinder engines and of 8-cylinder engines now selling in almost the lowest price class. It is now possible to buy an 8-cylinder car at about the price of a 4-cylinder car in 1926.

The only way in which a development of this kind could have been avoided was to have much larger engines in proportion to car weight. If we were to bring this ratio down to 10 lb. of car weight to 1 cu. in. of displacement, we would have much lower engine speeds and less difficulty with engine design, but it has proved to be far easier to make low-priced, fairly light engines run fast than it would have been to make the larger engine smooth enough even at a lower speed.

To show that it is easy to make a mistake and also that such a mistake may be of considerable value, I shall tell the history of the engine[2] I described in my paper of 1926 and subsequently built. From that paper it appeared clearly that eight horizontal cylinders, acting in four double-opposed pairs should make a very smooth-running engine. The idea seemed well worth trying and was especially interesting in view of the fact that it should not be possible to get any such engine into a motor-car; to try it was a good mental exercise. So I built such an engine, which happened to be practically the size of the present 16-cylinder Cadillac engine; that is, with a displacement of about 450 cu. in. In attempting to keep the weight down it was built with an aluminum crankcase, and a study of the cylinder blocks made the casting of the cylinders individually seem desirable as a means of weight saving, and this was done.

It was a strong, sturdy engine, quite capable of running for long periods at high speed; but, as a motor-car engine, I should say that it was a complete washout. The point overlooked was the great importance of absolute rigidity in the engine structure. To make an engine theoretically smooth-running is rather easy on the drawing-board, if rigidity of all its components is assumed; but, unfortunately, that rigidity must be built into the engine or the result is not as desired.

The mean effective pressure obtained in the average motor-car engine has steadily increased during the last six or seven years, owing partly to improved fuel and partly to improved valving and better combustion-chamber design. That increased power is very useful, but for satisfactory operation it must be accompanied by a correspondingly increased rigidity of structure. There seems to be no substitute for plenty of

[2]See The Journal, December, 1926, p. 590.

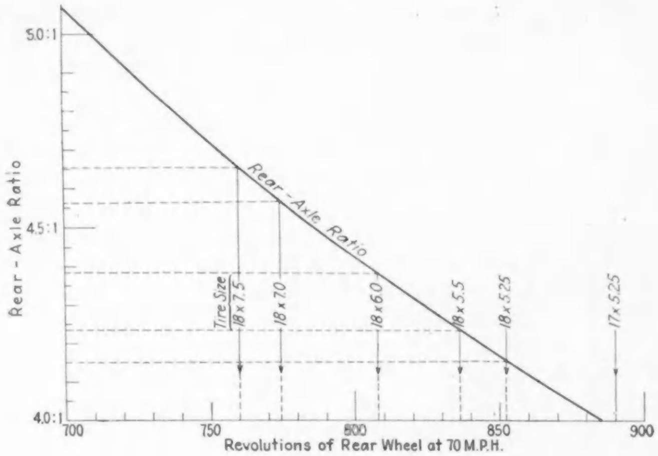


Fig. 1—Versatility Required of Motor-Car Powerplants

On the Average Figure of 110 Cu. Ft. of Piston Displacement per Ton-Mile and an Average Car Weight of 16 Lb. per Cu. In. of Displacement. Engine Speeds Must Be as Follows:

Car Speed, M.P.H.	Engine Speed, R.P.M.
60	3,040
70	3,550
80	4,060
90	4,570

cast iron in the right place in producing this result in engine design, but the mass should be accompanied also with as much compactness as is possible under the circumstances. For this reason the tendency has been continuously toward engines of shorter stroke and larger bore, thereby giving rigid crankcases and also much more rigid crankshafts.

Requisites to Smooth-Running Engine

Two requisites in the smooth-running engine are (*a*) inherent natural smoothness and (*b*) sufficient rigidity under the usual conditions of operation so that no vibrations are set up outside of the engine structure.

Some engines set up free forces that have nothing to do with the turning of the crankshaft. The four-cylinder and some V-eight engines, which are still in existence, are not in perfect balance. Besides the four and one of the V-eights (one will be discontinued this year), there are the cases of engines that apparently are without any considerable amount of free force but, even if the structure is correct in that respect, many other forces have to be taken care of in the operation of the powerplant.

Only very recently have we been at all sensitive to torque reaction. This has existed in all of our cars from time to time, but only with the softer mounting that has been used in the last few years has it become an important item in the consideration of what engine to use under any given circumstances.

Figs. 2, 3 and 4 are the familiar form of chart showing the operating forces present in engines of different numbers of cylinders. They are all based on conventional engines of the present four-cycle type. Fig. 2 shows the general form of curve of torque from pressure forces in engines ranging from the 4, 6 and 8-cylinder, to the 60-deg. and 45-deg. 12 and the 16-cylinder 45-deg. V. Even the last, with its many cylinders, shows a wavy line of torque reaction that can be noticed in the car when the critical period is passed through. The form shown is the shape of the curve at practically any engine speed, depending upon the amount of power being developed.

Fig. 3 shows the torque developed from inertia forces alone when the car is driving the engine. This also has proved to be a very important element in the later car design, although in the early days, when four-cylinder engines were common, especially of the sleeve-valve variety, the Knight engine suffered seriously from this over-run torque. Many Knight-engine cars, when pulling at 45 m.p.h., would feel fairly smooth, but when the throttle was shut off and the car coasted against the engine, a very considerable amount of vibration immediately appeared.

In the 16-cylinder engine set at 45 deg., or the 12 at 60 deg., the over-running torque reaction practically wipes out; in the straight 8-cylinder or the 90-deg. V-8, it is very small and in most cases is apparently negligible in operation.

The curve in Fig. 4, taken at 2500 r.p.m., shows the combined effect of inertia and the pressure from the cylinders. It will be noticed how very much better the 12-cylinder 60-deg. V and the 16-cylinder 45-deg. V are in respect to the torque reaction of combined pressure and inertia of the engines of more common construction.

Public Wants Big Cars

The tendency toward engines of increased numbers of cylinders was the result, not only of a demand for higher speed, but also of the demand for bigger cars. We have had much propaganda in this Country from many sources as to the beauty and advantages of small cars, but in my opinion, while the small car is considered to be very desirable for somebody else, no one that I have known likes a small car or will fail to use the biggest car that is available at the time, all other things being considered. That was the case in the early days and it is more the case now since speeds have become higher and higher. In the first place, the small car does not lend itself to high speed as readily as does the big car, other things being equal, because the wind resistance is proportionately much greater than the difference in weight. A big car may weigh twice as much as a small car, while the wind resistance may be only 25 or 33 1/3 per cent greater. The Model-T Ford weighed under 2000 lb. but the eight-cylinder Fords of today weigh about 2650 lb. The Chevrolet is now very close to 3000 lb., whereas the style of six years ago weighed about 2600 lb., and the speed at that time was at least 10 m.p.h. slower than it is today.

A decided limit exists beyond which the designer cannot go in striving toward a light car without running into very expensive manufacturing methods and eventually coming out

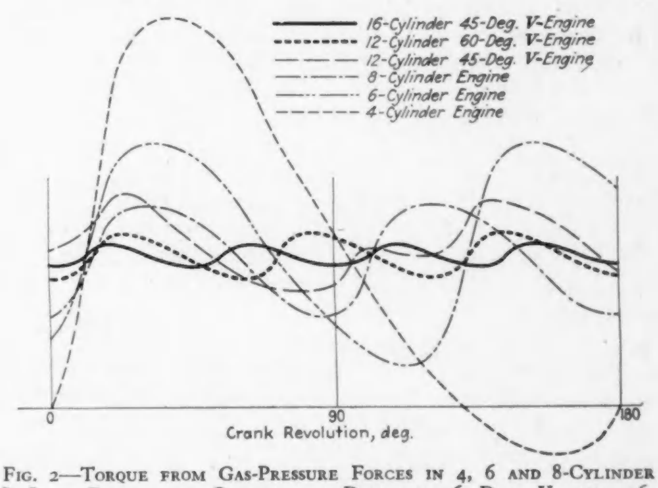


Fig. 2—Torque from Gas-Pressure Forces in 4, 6 and 8-Cylinder In-Line Engines, 12-Cylinder 45-Deg. and 60-Deg. V, and 16-Cylinder 45-Deg. V-Engines

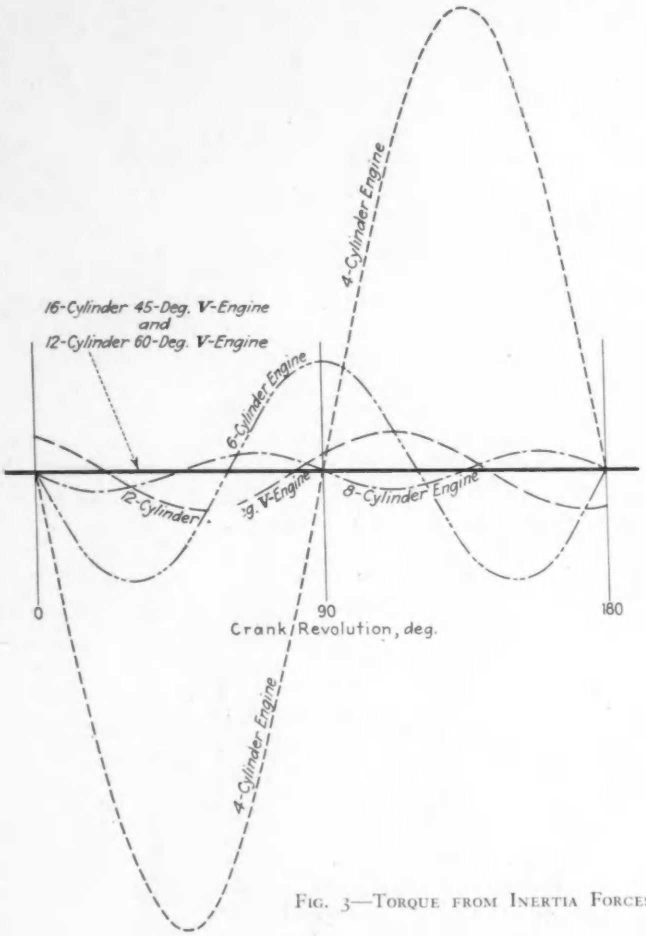


FIG. 3—TORQUE FROM INERTIA FORCES

with a car that has no advantage except that it is small. Considerable weight is necessary to obtain the required strength and rigidity, and the car buyer does not pay very much for weight.

Task Involved in Engine Reconstruction

The task of bringing the engines up to their present degree of efficiency and their ability to run fast has not been quick or easy. Nearly everything in the engine had to be modified and, in addition, shop practice had to be greatly improved to accomplish the result. Obviously, to make satisfactory block castings of eight cylinders is far more difficult than to make them of four cylinders, and it is especially difficult to make light-weight castings of multicylinder engines where the cylinders are of small size. Besides the difficulty of foundry practice, the machine-shop practice also is much more difficult. The cylinder of a big, slow-running engine can be much more badly machined and leak much worse without seriously affecting the result than can a smaller cylinder in an engine running at higher speed. Moreover, the lubrication of the high-speed engine has presented a very serious problem. I think that the oil-company engineers will back up that statement and also add that it has not been settled yet by any manner of means.

Engines of the old days probably did not exceed a speed of 3550 r.p.m., while in even very cheap cars they are now up to 4570 r.p.m.; and the difficulty of lubrication increases roughly as the square of the speed.

A number of changes in engine design have followed the general rearrangement of cylinders. The development of harmonic balancers for crankshafts has made possible high speed with smoothness and also has eliminated almost entirely the undesirable effects of long and not very stiff shafts, the result being that the straight-eight engine, which in its early days apparently had a considerable number of defects, now has proved to be an excellent type of engine, probably the best low-cost type, all things considered, that we know.

Carburetion has had to keep up with the greatly increased high speeds and with the greater number of cylinders. In the old days a plain carbureter having a fixed adjustment would work well with a four-cylinder engine having a speed range from 0 to 3000 r.p.m. It is no longer suitable in the updraft form for six cylinders and more, so some variable form of air-valve carbureter must be used to get power with high speeds. As a result, we have seen a great change toward the downdraft carbureter, which, while having a number of obvious deficiencies in operation, permits of rather larger openings without entirely compromising the slow-speed operation.

We have had a tremendous improvement in the manufacture of valves and in kind of material used in them, and today we see in large production a car having applied valve seats, a refinement which in the old days would have been considered suitable only for aviation practice. As that car is outside of our particular group, I am not ready to admit that the requirements cannot be met without that type of valve seat; in fact, I do not think we really need it yet, but that necessity has been reached in motorcoaches because of the very high engine requirements, and we shall probably come to inserted valve seats in private automobiles eventually if we do not do so at once.

The high-engine speed and the increased number of small parts have brought another load on the manufacturing department in the necessity for extremely close balancing of parts. That has been met by a development of crankshaft balancing machines for running balance that really are of a production kind and permit a very rapid operation, and also by the development of shop practice to make the weight of all the manufactured moving parts alike; that is, instead of attempting to group pistons in sets of four, six or eight, as the case may be, it is now becoming common practice to

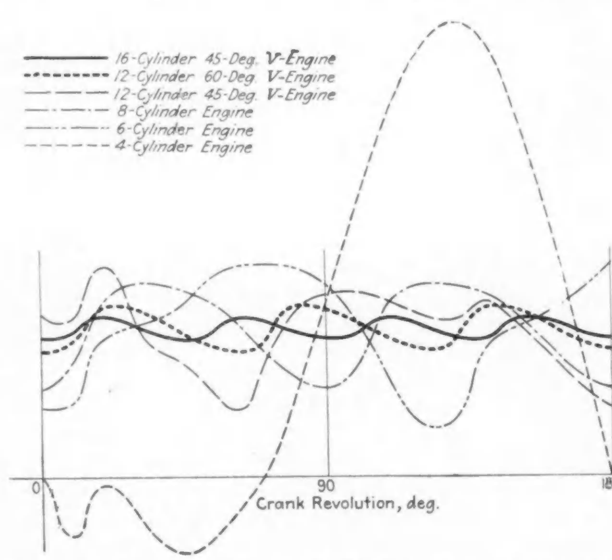


FIG. 4—COMBINED TORQUE FROM GAS-PRESSURE AND INERTIA FORCES AT 2500 R.P.M.

make all pistons the same weight within very close limits. The same is true of connecting-rods, not only as to weight but also as to position of the center of gravity.

The limits applied to crankshaft accuracy also are much better than they have been in the past. It is absolutely essential that this be so or we should lose a considerable advantage otherwise gained by the addition of more cylinders. An eight-cylinder engine with one tight piston in it will feel extremely rough in operation, possibly even rougher than a four in some conditions.

At the same time the much higher compressions that are being used require a higher degree of accuracy to produce tightness, for without gas-tightness, proper lubrication and continued high-speed operation are impossible. As nearly as we could tell from experience with aviation engines during the World War, the effect of leakage goes up at least as the square of the compression pressure. In cylinders the possible leakage areas vary in proportion to the square of the dimensions, while the volume which can leak goes up as the cube. This means that the smaller the cylinder is, the more important it is to have accurately fitting pistons and rings and true, straight cylinder bores.

Large, Heavy Cars Require Great Power

While high speeds have been obtained in the smaller cars by increased power within the limits of eight-cylinder engines, the larger and heavier cars with their greater wind resistance have required greater and greater power to accomplish the desired result. It is now rather common to have 150 to 160 hp. available in commercial passenger-cars.

The increased size of passenger-cars was humorously shown within the last two years on the Queensboro Bridge, where three traffic lanes were laid out by the city authorities to accommodate cars going between Long Island and New York City. The measured center distance of these three traffic lanes was but 1 in. more than the spread of my own Cadillac car over the fenders; that is, if one kept strictly in one's own lane, a car alongside would have 1-in. clearance outside of the fenders. The width of the wheel track actually was narrower than the over-all width of the tires on several existing cars. In checking up at that time I found the over-all widths of comparable cars had gone up from 7 to 8 or even 10 in. in the 15-year preceding period. Considering cars of the larger size, it is obvious why considerably more horsepower is required to meet the high-speed conditions.

The Cadillac 16-cylinder engine was not designed originally for production, but to be in advance of development. The 8-cylinder engine, as brought out from year to year, merely kept up with the increased weight of the car, and the engineers decided to bring out one powerplant that would be big enough to produce any desired power. They certainly did it, but the result had a far-reaching effect on the industry, and I doubt if many realize how much of the present engine development has been the result of that particular demonstration. That car, when first shown, could be driven at 50 or 60 m.p.h., the clutch withdrawn and the engine allowed to idle, and the driver was almost unable to tell whether the engine was pulling or not pulling. At that time the opinion seemed to be that the public liked the noise that engines produced when pulling at high speed. The noise made by the air rushing into the carbureter was called a power roar, and, although some of us protested, the condition persisted until the 16-cylinder engine demonstrated the great attractiveness of the feeling of coasting at any possible speed. As a result of that particular car, rapid developments were made in inlet and exhaust silencing and in making smoother-running engines, but, above all, in mounting engines so that whatever vibration might be induced in the engine would not be transmitted to the car and passengers.

Motorists Prefer Freedom from Vibration

There were two very interesting examples of the beginning of "floating power," which was certainly a happy choice of a name. However, the type of engine suspension existed a year or two before it was applied on the Plymouth, having been used originally in the Pontiac eight, formerly the Oakland eight. That engine was a reversion to the original eight-cylinder V-type, in which a flat crankshaft was used, resulting in certain free forces that caused the engine to vibrate. The Oakland engine was hung in such a way that it could vibrate without carrying the vibrations into the car. For some reason it was regarded as poor practice to have an engine vibrate, and therefore nothing was said about the floating-power-unit mount; in fact, it was discussed rather apologetically if at all. However, a year or two later, Plymouth, with a four-cylinder engine that suffered from the same unbalanced free forces, came along and a mounting was developed which took care of those forces to a large extent and also took care of something that the Oakland did not have to contend with; that is, the serious torque reaction both in pulling and in over-run.

That car demonstrated something that I believe no one had expected; that was that many other unsatisfactory feelings were wiped out at the same time that these major disturbances were eliminated. We then had in all cars a certain amount of torque reaction at certain speeds that could be felt. We also had in the cars vibrations produced by lack of rigidity in engine structure. The Plymouth, with its great mass of rubber mounting, cut off the access of all these minor vibrations to the car and gave a very pleasant feeling at any speed; in fact, a feeling approximating under favorable conditions that of even a 16-cylinder Cadillac or a very good 12.

I do not know the advertising value of the name, but the advertising value of the accomplished fact was extremely important. The engine mounting made a very satisfactory car out of one that previously was quite ordinary. Although this floating-power tendency began, I think, within the last two years, an examination after the first of the year of practically all new cars of six cylinders or less probably will show engines that very distinctly move in the chassis under variations in load.

To smooth out the torque reaction of the six, which actually consists in sufficiently lowering the speed at which the torque reaction is apparent, it became necessary to soften the mountings so that engine movement is very noticeable. If the idling is irregular or if the throttle is suddenly opened or any similar occurrence takes place, the engine will be seen to move. The eight-cylinder engine, with its far better control of these conditions, does not require such a soft mounting and, in most such cars, the engine apparently is fairly solid. However, this is only apparently the case.

Soft Engine-Mounting Forced Chassis Redesign

This trail along which the engineers have gone during the last two or three years has led from the mounting of the engine to a complete revision of the whole chassis structure. I do not believe that anyone realized how large a part was

played by the powerplant in bracing the frame until he tried something on the order of flexible mounting. The whole practice of frame design had to be overhauled and changed, and frames that are more complicated in layout and far more expensive in construction have been the result. The engineers had to attack this problem at the same time that they were getting into higher speeds and therefore more difficulty from lack of stability in steering, leading to shimmy or tramp or other high-speed troubles, and also difficulty with fender and radiator shaking and other things of that kind.

HIGH SPEED must be accomplished with safety. Even the best cars are none too good in this respect, and the worst performers at high speed have no business on the road. Steering-gears have not kept pace with the possibilities of the engines for higher speed; whereas present cars require a steering-gear ratio of 18 or 19 to 1 for traffic and parking, we should have 14 or 15 to 1 for high-speed driving. A compromise between these is not wholly satisfactory for the two extremes of operation; both engine performance and steering should accommodate themselves to low-speed driving in cities, with good acceleration and parking ability, and to sustained high speed on level roads and on hills.

As a further contribution to this year of depression, so far as the engineers are concerned, the tire companies have seen fit to bring out a super-balloon tire, which requires further changing of important chassis parts if they are to be a success.

Up to the present we have been able to accomplish with the cheapest of materials all of the engine results that have been obtained, which is very satisfying from many points of view and will continue to be the case, I believe, as long as a low-price fuel is available and the cost of tires is as low as at present. Cast iron is a very humble material but for certain uses it is very hard to beat.

I think no one has invented a new way of making a cast-iron piston for a long time, but almost weekly we read of a new way of making a perfect aluminum piston to replace the perfect aluminum piston in use during the past year. I believe we shall be able to retain cast-iron pistons even for high engine speed. There is no question that, when the engineer is caught with an engine a little too small for the car and has to modify the 16 lb. per cu. in. of displacement to 18 or 19 lb., thereby increasing the engine speed by 10 or 15 per cent at a very inopportune time when the crankpin bearings are already on the verge of being overloaded, an aluminum piston helps a lot in getting out of the hole. Also, the use of aluminum pistons is a great aid in ameliorating the torque from inertia forces, especially in four and six-cylinder engines. The aluminum piston has its good points on its face, and the bad points are hidden until the owner has had the car for a year or more.

In the field of larger engines such as are used in buses and trucks, we have only just begun to feel the change toward a more complicated construction. In most cases the six-cylinder engine has been able to carry on to advantage, some of these having now reached a size of 700 to 800 cu. in. and corresponding power. The White Co., in the effort to obtain a very compact, powerful powerplant to go between the floor of the vehicle and the road, has constructed a 12-cylinder, double-opposed, horizontal engine, and the results of its use will be watched with much interest. It should give a much smoother and quieter operation than has been customary in buses and thereby add greatly to the comfort of the passengers.

Better Transmissions Affected Engine Designers

Another load that has been thrown on engine designers has resulted from much better transmission construction. Not only is it possible now to shift gears at relatively high speed with comfort, but gears have been made quiet at virtually all speeds, with the result that owners will operate in second speed to car speeds that in the old days would have seriously compromised the engine result. The 16-cylinder Cadillac, with its relatively small cylinders and careful construction, operates safely and comfortably at 40 m.p.h. in first speed, which is a good traffic speed when one is in a hurry, and around 65 to 70 m.p.h. in second. One advantage of the multicylinder engine of that type of design is its rapid accelerative ability, as it has very large displacement and very light spinning weight.

An interesting fact with reference to the importance of muffling both the inlet and the exhaust in high-speed engines is that the six-cylinder engine is particularly difficult in both respects. The sequence of pressures in the inlet manifold and exhaust manifolds seems to be ideally suited to start resonance effects in the piping, and a change in the length of chassis, necessitating a change in the length of the exhaust system, requires a completely new tuning of the exhaust in most six-cylinder engines and also in 12's, which are distinctly similar. Eight-cylinder and four-cylinder jobs are considerably better in this respect.

Silencing of the inlet, which has been a very important part of the program, has resulted largely from the importance of higher engine speed. Greater overlap of inlet and exhaust-valve opening in the attempt to get higher speed by valve timing has a great tendency to increase the noise in the inlet system, so the air-cleaner is now being used for something that is really worth while; that is, cutting out noise.

A big advance has been made at the other end of the car in the use of the tuned muffler system. Formerly the muffler was used largely as a means of stopping the noise after it had been produced; today mufflers are available in a number of types that prevent the production of noise and operate with almost no back pressure at any speed. The changes in muffler and exhaust pipe this year have made possible the operation of a considerably heavier line of Buick cars with the same powerplants and equal or better performance than previously, which affords a production economy that is well worth while, considering the cost of changing a set of engine tools.

Good Prospect for Eight-Cylinder Engine

As I see the immediate future of the passenger-car engine, we can go further along the path we have been following, the speed with which we travel being dependent upon customer demand. The prospect that the last new model of four-cylinder car, in cars of present size, has been produced seems to be extremely probable. The public has shown a definite indication that it prefers the eight-cylinder at a price $50 higher. The future of the eight-cylinder in the low-price field depends upon how good a manufacturing job is done. I believe that this engine can be very economical, not only in first cost but also in upkeep and cost of operation, if it is properly built. However, because of the gas-leakage difficulty, the temptation is great, when building an eight-cylinder engine of small capacity, to use a large

number of rather stiff piston-rings, with the result that the engine friction is considerably higher than would be that of a six or a four of the same capacity, and this causes a considerable waste of fuel.

Both theory and actual tests indicate that the four, six and eight of equally good construction should give about the same over-all economy performance. What the final result will be is uncertain until we have more completely worked out the heat control. Considerable heat must be used on the inlet manifold of any car, but the six seems to require more than either the four, which can be operated in most cases with almost no heat, and the eight, with twin carbureter, which lies somewhere between the four and the six. This heat is not so necessary for full-power operation but is needed to obtain the high degree of flexibility and the rapid acceleration that customers demand. The effect of heat is to cut down the capacity of an engine of any given size under full load and thereby require a slightly higher engine speed to produce a given result. A good comparison was afforded last year in the De Soto and the Plymouth, which were almost identical cars except that the De Soto had a six-cylinder engine that was considerably larger than the Plymouth four, with about the same maximum speed and a very little better acceleration at low speed.

As for bodies, I believe that we shall depart from carriage tradition but should be cautious about incorporating extremely radical features in design. Full streamlining is not good looking in itself and requires a very long car, as a stubby front destroys the impression of speed.

I hope that we shall soon stop making our cars lower. There is scarcely room now to get the necessary machinery between the floorboards and the road surface, and some of the present low cars are lacking in comfort.

Present bodies are very safe and I believe we shall soon see something good in the way of ventilation; however, air-conditioned cars, in my opinion, will not come for some time because of the cost, the additional weight and the power required to operate the cooling system.

Independently sprung wheels offer attractive possibilities for improved roadability, and automatically controlled shock-absorbers of high efficiency will regulate the ride so that it will be much more comfortable.

We are not yet ready for adoption of 9 or 10-in. tires and very low pressures, but we shall have 6 and 7-in. tires on small cars.

Two or three years probably will be needed to get the new type of body and fender design and other features to suit the new tires. I do not believe in giving the public a tire that needs to be held to very narrow limits of pressure.

All of the opinions expressed in the foregoing are my personal views and are not to be taken as those of the corporation with which I am connected.

THE DISCUSSION

Hubert Walker[3]:—Mr. Crane made a remark about a general tendency to the short stroke. I believe that he meant that to be taken with some reservation. He pointed out that engine speeds are going up, and obviously we cannot go on increasing the bores indefinitely and still meet those speed requirements. The inertias continue to increase with the speed, and a limit exists to the size that will take the bearings. At a speed of 4000 to 4500 r.p.m., about 75 cu. in. per cylinder will be the maximum displacement and, with an engine running at 3000 r.p.m., this would possibly go to 100 cu. in. I believe that in the bearing loads and inertia forces there would be limitations beyond which one could not go and produce an engine for continuous service that would stand up.

The reason for making these large bores for short strokes is to produce a stiffer crankshaft. I believe that also is due for some modification, because one would sacrifice some thermal efficiency if he carried that to the extreme, and it is well to have a little better balance between the bore and the stroke, gaining a longer stroke and more efficiency, so long as the bearing sizes are within reason. This will also give an overlap between the main bearings and the crankcase, and in that way make possible a little shorter engine and as stiff a crankshaft as one could get the other way and keep the bearing loads down.

Mr. Crane also mentioned that the torque reaction of the Cadillac 16 was noticeable at certain speeds. I believe that any 16-cylinder engine spaced at 45-deg. power impulses would give practically a synchronous torque curve. Normally the 12 would have the 60-deg. spacing, but when Cadillac built the 12-cylinder engine, 45 deg. was adopted. As a result, a non-synchronous torque curve was procured and the engine was found to be actually a little smoother than the 16.

I agree with Mr. Crane that nothing yet indicates that valve inserts are needed. If the valve seats are properly cooled and the cam design is right so that the valves open and close rather quickly, erosion and wearing of the seats will not occur. I know of several engines that have gone better than 60,000 miles without valve grinding or showing any sign of seat erosion or wear on the valves, and those valves are without inserts. Adding inserts apparently would produce an additional problem of cooling. There again the cylinder-bore size will affect the valve size and there will be increased inertia due to the valve trains, another factor in the limitation of cylinder sizes.

Recently there has been a trend to simplify the valve train and reduce the number of working parts in it so as to have faster valve opening and closing, which has limitations in quietness. The reduction of parts reduces the clearance, and the wear that occurs causes less valve trouble.

Bore-Stroke Ratio a Matter of Engine Type

J. W. Oehrli[4]:—The question of bore-stroke ratio is determined to a great extent, I believe, by the number of cylinders one must consider. Comparing a straight-8 and a 12-cylinder engine, preferably of opposed type, this problem comes up: Strokes have been decreased in the last few years until we have now about reached the limit that is possible without producing a cumbersome engine; in other words, if we want to decrease the stroke of the straight-8, we must increase the bore to maintain the displacement. On the other hand, with an opposed 12 of the same power, we find that, with the same bore as in the straight-8, the stroke will be de-

[3]M.S.A.E.—Chief engineer, American LaFrance & Foamite Corp., Elmira, N. Y.

[4]M. S. A. E.—Graduate student, Yale School of Engineering, New Haven, Conn.

creased two-thirds and the engine will be much shorter. Therefore, is not a still further decrease in the stroke very desirable?

H. M. Crane:—From the remarks of both speakers I seem to be still thought to believe in a certain set of fetishes. If I ever did believe in them, I have had all that thoroughly knocked out of me in recent years. I do not believe in the long stroke or the short stroke or any other combination except as the circumstances may seem to make a certain combination desirable. As a matter of fact, the crankshaft construction is far better in a short-stroke than in a long-stroke engine. I think the industry has suffered seriously in the last three years from the attempt to put straight-eights where sixes grew before.

We have had some experience on that in the Pontiac. The Pontiac straight-eight engine was designed primarily as an engine, without reference to any particular length of chassis or similar considerations. It is the smoothest running eight-cylinder engine that has been built at anything like similar cost. It does not look very different from other engines but has a sufficient length to make it a good engine. It has the length that every six has been given when it has been designed to be satisfactory. There is plenty of water space between the valves and around the various ports, and, in addition, the crankcase has ribs on the sides that are carried below the crankshaft, producing an extremely rigid over-all structure. That engine, with its stubby crankshaft, good jacketing and cool inlet charges, can run with a 5½ and even 6:1 compression ratio with greater smoothness than has been common with engines of 4½ to 5:1 compression ratios. Not only is it smooth in that respect, but also in its ability to turn over at high speed without producing extreme vibration.

Will Find Place for Longer Engines

I should say that there is every indication that we are going to find a place to put longer engines. The latest trend in motor-car style is toward a hood well forward over the front axle; the day when the axle was placed directly under the radiator has passed. The Plymouth is the first example of that type of design that has come to the public, but you will see more such cars and the tendency will go much further, perhaps, than Plymouth has already gone. Therefore there is no reason for being discouraged about the length of a straight-eight engine of moderate size. It is true that, if it is very necessary to save length and you must have eight cylinders, the bore-stroke ratio must be sacrificed and you also must sacrifice cooling around the valves. As an engineer, I have been ashamed in recent years to see the cut-open straight-eight engines that some manufacturers have exhibited at the automobile show—no water between the valves and usually a very hot surface adjacent to the inlet port where the heating would do most harm, all resulting from trying to make a straight-eight go in the place where a six should go.

Mr. Oerhli was correct in saying that, when there is not room for a big enough straight-8, it is better to go to a 12. I think we shall see more 12's in the future, partly on account of length and partly for the reason he stated, that a proper bore-stroke ratio can be used within a reasonable length and the pistons and cylinders kept of moderate size, allowing high engine speed.

Circumstances Forced High Engine Speed

I do not want to be understood as recommending the relations shown in Fig. 1. That chart represents only the existing state of affairs. It shows the ability of a car that represents substantially the engine load indicated. We have cars weighing as high as 16 lb. per hp.; that is a common weight. Some cars, like the Cadillac 16 and the Ford 8, have a considerably lower weight ratio, but that is a good average, and, with the tire sizes and the ratios between the tires and the engine, those are the actual speeds at which engines are running today.

I do not mean to imply that they should run that fast or slower. I am neither a slow-speed nor a high-speed crank. I simply say that, by force of circumstances, we have been going steadily up in maximum speeds until now we are reaching 4000 r.p.m. and may go higher, and the only alternative to that is to use bigger engines in proportion to car weight, for we do not know how to build slower-running engines of light weight that seem to be nearly as good as the commercial kind we are building today. Until we get a new kind of material, we probably cannot.

I mentioned torque reaction of the 16-cylinder Cadillac to show that it can be felt in almost any car when the engine is nearly rigidly mounted. When the 16 is supported in any amount of rubber, it is sensationless; even with a stiff mounting, only an experienced observer can pick out the period in it, but it is there and can be found by looking for it.

Combustion-Chamber Problem Still Baffles

A. L. Beall[5]:—I should like to get Mr. Crane's ideas on present combustion chambers and the future of them, and what his thoughts are on new methods for cylinder heads or combustion chambers.

We had a statement from him on pistons; I should like to know what he thinks of the possibilities of other metals in cylinder heads.

Mr. Crane:—I belong to a group of engineers, which I think is not very select, who used to think they knew a great deal about combustion-chamber design but are now quite sure they don't. We certainly are doing better all the time, but I believe no one can predict exactly what any combustion chamber will do in the way of giving all the desirable qualities that we are seeking. It is easily possible to develop a combustion chamber that will have a maximum knock rating, but, unfortunately, many of these are extremely rough in operation. The engine does not make an audible knock but develops a type of indicator card that gives a very unpleasant feeling in the car. The real difficulty is to get a combination of knock suppression and smooth operation. It is very difficult to find that quality on the dynamometer. I developed a set of heads in New York City for a car and the engine showed very good qualities on the brake and in high-compression ability and apparent smoothness, but in actual practice it was distinctly lacking in the latter respect.

Other elements that enter the problem are gasoline economy and the ability of the engine to operate at part throttle. Those conditions are seriously affected by the spark-plug location, and that also has a great deal to do with the smoothness and the ability to carry high compression. The variables are so many that finding the solution seems to be a cut-and-try operation from previous experience, using a general set of principles.

[5] M.S.A.E.—Refined-oil department, Vacuum Oil Co., Inc., New York City.

That is one difficulty with short-stroke engines having fairly large valves and the high compressions we are now using; we are being more and more limited as to what we can do as to the shape of the combustion chamber of an L-head engine. It is very important to get a good free exit from the valves, that is, space is needed over the valves, and when the chamber is designed to be the best that way, it seems to work out fairly well in other respects if the spark-plug is correctly located. That does not apply to overhead-valve engines, in which we cannot do much except try to get the spark-plug in a fairly good place.

Cast-Iron Best for Cylinders and Pistons

As to other cylinder-head material than cast-iron, I am very pessimistic, for practical reasons. Even with the compressions of five or six years ago, it was no idle job to get a gasket to hold tight with the available compression provided by the number of studs that could be put in the space one had; with any metals such as aluminum with its variable expansion and lack of rigidity, the difficulty becomes far greater. In addition, the ability of the aluminum to carry higher compression is not so good after the engine has been run for a while and the head becomes carbonized on the inside and oxidized on the outside. Therefore I think that no material is available yet that is much better than cast iron for an ordinary commercial automobile engine. I can see no great objection to using aluminum pistons in large commercial-vehicle engines in which cylinder sleeves can be used, but that is very different from using them in passenger-cars.

I may have been misunderstood regarding valve seats. I am not advocating inserted valve seats, although they are the foundation of the most successful aviation engines at the present time. Both the Wright Aeronautical Corp. and the Pratt & Whitney Aircraft Co. use them exclusively and of necessity, because the engines have aluminum cylinder-heads which do not produce very effective seats. In a passenger-car engine made of a good quality of cast iron, there is no reason as yet to use anything in the way of a special valve seat if other parts are correctly designed, but it seems to be worth while in engines of greater power and capacity.

Doubts Automotive Future of Diesel Engines

E. B. Neil:—Would Mr. Crane care to say anything about the possibilities of the Diesel engine in a truck or car?

Mr. Crane:—I cannot see the Diesel engine for trucks or other work of that kind any more today than I could in the past. It is being used abroad to evade gasoline taxation and may be used that way in this Country, though why any government should permit of evasion in that way I do not understand.

I think the Diesel engine suffers from all sorts of inherent difficulties so far as motor-car use is concerned, even on commercial vehicles. I do not remember ever hearing any claim for it except greater economy of operation, and there seems to be a great deal of doubt about that if it were operated on a comparable basis with the gasoline engine, especially if time is any element in the consideration and we have real bookkeeping on the cost of upkeep and on depreciation. That is only my opinion, but it is getting a little stronger as time goes on.

When a number of very able engineers have been trying for 10 or 12 years to introduce the Diesel in a service of that kind and have not succeeded yet, I begin to think maybe they will not and that there are fundamental reasons why they should not; I am even sure of it.

A series of articles that thoroughly give the status of the Diesel engine has been published in *Automotive Industries*.[6] So far as fuel is concerned, the difference in cost is negligible at present at the refinery, which is, after all, where the comparison must be made. It is not fair to charge gasoline with the present system of distribution, which makes it a desirable and useful fuel, and refuse to do the same with Diesel-engine fuel if it is going to be used in the same way.

The interesting thing about the fuel is the difficulty of getting people to use any special kind. Many commercial operators do not even use good antiknock fuel. I have been told that Diesel equipment for road building and similar services was looked upon with favor by contractors because the workmen did not find it worth while to steal any of the fuel to use in their own cars.

Smoothness of Operation Important

E. H. Gebhardt[7]:—Mr. Crane stated that the Pontiac engine could run on compressions from 5½ to 6:1. I am wondering about bearing loads and the desirability of operation on a compression carried up to 6½:1 in an individual car or any group of cars, provided sufficiently high antiknock fuel is used.

W. E. John:—Why was the V-type engine in the Pontiac abandoned?

Mr. Crane:—Evidently I did not make mystelf very clear as to the compression ratio. What I was attempting to convey was that this engine, because of its design, rigidity and general adequateness, is able to run with compressions as high as 5½ or 6:1 without objectionable roughness. I do not say that such compressions are desirable; I do not think they are, but the Pontiac will operate above 5:1 on ordinary commercial gasoline. The point I was trying to make is that this is not due to its being designed that way but to the ridigity; it could handle the high compression and still be a smooth-running engine. That is a point that is becoming more important.

Straight-Eight versus V-Eight

The question of the straight-eight and the V-eight is largely one of engine size. The manufacture of the V-eight presented some fairly difficult foundry practice and that difficulty has never been entirely overcome. The castings cost considerably more than they apparently should, and the company never has been able to improve that condition. I understand that the Ford Motor Co. has had the same trouble. Moreover, the V-eight engine, with a type of crankshaft in the Pontiac and the Oakland like that in the old Cadillac, is not inherently in running balance; it has free horizontal forces that must be canceled out in the mounting. This was done rather satisfactorily when the Oakland was first brought out, by employing, as I described, practically the first floating-power mount that was used; but today the public appreciation of smoothness has advanced to such an extent that that no longer seems to be adequate. If the Oakland or the Pontiac had been continued with a V-eight engine, the company probably would have gone to the 90-deg. crankshaft with counterweights, which would be in perfect running balance; but that makes increased cost and, when all is said and done, all that is gained is a short engine.

[6]See *Automotive Industries*, April 16, 23 and 30; May 28 and Sept. 24, 1932; also *Commercial Car Journal*, June, 1932.

[7]A.S.A.E.—Designer, Godward Gas Generator, Inc., New York City.

The straight-eight engine is the result of five years of work by those engineers, and they have been all the way around from one type to another, ending with the straight eight because, despite its apparent deficiencies on the drawing-board, it is a very good automobile engine. It has been made possible by improved foundry practice and also by the knowledge gained regarding crankshaft design and the use of harmonic balancers on the crankshaft, which make a long, slim crankshaft rather advantageous than otherwise. The engine is cheaper to build than the V-eight, and, if the two should be compared, I think the straight-eight would be found infinitely smoother in operation and far easier to service.

The public feeling regarding the appearance that we are coming to more and more and that we shall be getting to next year is such that the increased length of the straight-eight engine seems to be an advantage rather than an objection.

Cold Carburetion Presents Difficulties

Mr. Walker:—Would Mr. Crane care to say anything about the possibilities of fuel injection replacing the present method of carburetion as a step of the future toward increasing the power or displacement of the engine?

Question:—Will he also talk about cold carburetion or a similar subject?

Mr. Crane:—No work is going on in the corporation, so far as I know, looking toward a commercial application of fuel injection.

Cold carburetion has been worked on for a long time, but so far it has been very difficult to produce a system of that type that could be assembled on the car on an assembly line and that would produce the same result as on a test engine. Little elements in the adjustment of particular cars seem to require special treatment in each case, and this has prevented the commercial application of cold carburetion, although its advantages in allowing operation without any applied heat are very apparent.

As a rule, the cold-carburetion jobs have a tendency to feel rougher than the regular jobs; that is also likely to be the case in downdraft carburetion. We tried both in some of our cars and one could almost pick one out from the other when driving, the rougher feel of the downdraft engine probably being due to the same cause that makes the cold-carburetion engine feel rough.

Possibilities of Flat, Opposed Engine

Herbert Chase:—How does Mr. Crane feel about the future of the flat, opposed engine in passenger-car work? Suppose we come in the future to mounting the engine in the rear where a greater width is possible; will not the flat engine permit decided advantages?

Again, what does he consider to be the possible future of the two-stroke cycle? May it not be the answer to securing more power from the small, compact engine and gaining light weight, still maintaining reasonable rigidity?

I should also like to hear his views with respect to the use of some of the alloy cast irons for crankshafts.

S. B. Barnard:—With reference to a rear-engine car, where of necessity the radiator capacity is limited, and with the continual increases in compression ratio, what are Mr. Crane's views as to high-temperature cooling and the possibilities of an engine that is liquid cooled as a self-contained unit without a radiator?

Also, what are his impressions as to the field for air-cooled cars, eliminating the plumbing system that has been the trouble-maker in automobiles ever since they started?

W. S. Peper[8]:—A development that seems to be gaining ground in connection with streamlining and which looks rather promising is the building of the body wider in the mid-section, with a front seat for three persons and a rear seat for two, bringing the body line straight forward, using the conventional chassis we have at present. Mr. Crane might comment on that while discussing streamline cars.

Mr. Crane:—After two or three experiences with building an engine of the flat type, I became considerably discouraged. In discussing engines in general, I might well have said something regarding the difficulty of carburetion produced by unfortunate cylinder arrangements that require a bad type of manifolding.

The flat-eight engine laid out in the optimum way with respect to crankshaft and bearings produced a very unfortunate layout as regards carburetion. We never really made a very good engine of it, no matter how it was modified. Improving the manifolding characteristics would introduce considerably greater difficulties in the layout of crankshaft and bearings. However, as a general principle, I go a long way in making special bearing layouts to make the manifolding easier, because that is well worth while.

Rear Mounting Will Create Many Problems

I do not think we can attack the question of a suitable powerplant for a rear-engine car until we have a fairly good idea of just what car shape is best and what space we shall have for the engine. We shall find the right way of putting the powerplant in the necessary space when the time comes. The engine may be a V or flat, opposed eight or a flat eight on its side. I think a flat straight-eight will be perfectly good.

A question was asked as to the possibility of smaller engines in streamline cars which will permit higher speed with less horsepower. In some ways the engine designer's problem probably will be harder with rear-engine streamline cars than it is now. Acceleration of the car from standstill up to 30 or 40 m.p.h. is largely a product of the car weight and size of the engine. A small engine might produce ample power for high car speed yet not be big enough in relation to car weight to accelerate from traffic lights in the way that will satisfy the owner. If the engine is small in relation to car weight and is geared to produce reasonable hill-climbing ability, the engine speed will be not 4000 r.p.m. but around 5000 r.p.m., because much lower axle ratios will have to be used to get the 110 cu. ft. necessary in climbing hills at 20 or 30 m.p.h. For that reason I think streamlining is going to make more trouble for the engineer; it certainly will not help him out of any of his present troubles.

Mr. Chase also raised the question of two-cycle engines. In general, two-cycle engines have a tendency to run better at one speed than at any other speed, producing a humped power curve. They can be designed to produce maximum power at 2000 or 2500 r.p.m. but do not seem to be able to produce a good torque over a wide range of speed. Neither do they seem to lend themselves characteristically to high engine speeds, and, when built large enough to run at slower speeds and give equal power, still using material like

[8]M.S.A.E.—Account executive, Stewart-Davis Advertising Agency, New York City.

cast iron, they become as heavy if not as bulky as a four-cycle engine.

So far as making crankshafts out of cast iron is concerned, although I have not kept up with metallurgy very much, I think it would be largely a question of bearing surface, because, owing to the necessary rigidity of the engine, crankshafts can be made of fairly low-grade material provided the bearing surface is satisfactory.

Alternative Methods of Cooling

Fortunately, high-temperature cooling in cars has not been pushed on us yet. In airplane practice it is obviously desirable to find some way of effecting the transfer of heat to the air at a higher temperature. The air-cooled engine runs at a very high temperature, representing about the maximum safe cylinder temperature, and attemps to bring the water-cooled engine up to it have been natural, though I regret that we may have to do it.

Tests made at Wright Field with Prestone cooling indicated that, while the radiator was of a more favorable size when it had an outlet medium temperature of 212 deg., the engine was running higher cylinder temperatures than when using water-cooling with the same outlet temperature; so, in improving the efficiency of the radiator, you decrease the efficiency of heat transfer from the engine to the cooling medium. In a cast-iron engine, with the limited amount of space available around the valves and cylinders for cooling, especially around the valves, we can hardly afford to lose any of that valuable quality simply to allow the use of a somewhat smaller radiator. So far we have always been able to find plenty of room to put the radiator on the car, and car speeds were not high enough to make the extra air resistance a serious matter.

The public has rather definitely taken its stand as to air-cooling. The facts are that an air-cooled powerplant for a motor-car is far more expensive than is a much better water-cooled powerplant made almost entirely of cast iron and very low-priced steel, and, while the total poundages may be a bit more, the cost per pound is much less and durability and all other factors are greater. The slight trouble from a water-cooling system, or, as people say, "plumbing", on the car, does not seem to bother automobile owners a great deal. They have become accustomed to it, and actually the system does not give any more trouble than various other things one must put up with on air-cooled cars.

Seating Layout Undergoing Change

The arrangement of three-passenger front seat and two-passenger rear seat is not new except as applied to a completely closed car. The best-known five-passenger car among the youth is a sport roadster, which seats three in front and two in the rumble seat. That is a good layout, in my opinion. In this Country we are committed to a three-passenger-front-seat car; that is, one in which three can crowd into the front seat. That is the only combination that is really satisfactory when there are three persons in the party. In such a case you always have three in front, and it is a lot more fun—with the right people, of course.

The question of the two-passenger car seat is interesting. The answer may be tied up with streamlining, and we do not know what the answer is going to be on that; in fact, the more we study the possibilities of streamlining motor-cars in the available length for any given size of car, the less optimistic we are of getting a really good result. With the necessity of having four wheels on the ground, of preventing the throwing of mud and dirt, and the fact that we must have head-lamps and many other external appurtenances, it is surprisingly difficult to make a good streamlined design, and the cars certainly do not look very attractive when you get one.

Sir Dennistoun Burney's car[9] was an interesting example in many ways, but with the 157-in. wheelbase and very long overhang, nobody would want to handle that car in close traffic or in parking, and that is certainly an element that must be considered.

Cars Too Low for Convenience

Ashley C. Hewitt[10]:—When are we going to get back to the design of car that a man can get into conveniently and see out of when he gets in? I think I am not alone in wanting that. Although I am of moderate size, I cannot get into any car on the market today with an ordinary felt hat on, a top hat being out of the question, and I usually have to wear a golf cap or take off my hat.

Mr. Crane:—Whenever the public decides that it would prefer a car higher than the present type of car, it certainly will get it. The engineer is suffering today because of the insistence from the sales department to make cars lower and lower. We see cars judged as to their desirability by putting a sort of gallows frame over one and then another to show that one is 2 in. lower from the ground to the roof than the other one is. Personally, I think that some of them have been getting too low for good appearance, not to mention comfort. There is no question that they are uncomfortable or about the difficulty of seeing out of many of them. Continual pounding by some of the engineers has resulted this year in most of the General Motors cars being made to afford reasonable visibility from inside. As an engineer I would welcome any concerted demand from the public in that respect, for it is a tremendous job to hide the machinery between the floor and the road and have some road clearance, especially since we have had the softer engine mountings and more rigid and difficult frame construction.

M. C. Horine[11]:—I should like to get the record straight. I did not understand that this was distinctly a passenger-car meeting. While we have various business interests, we are all customers of the passenger-car builders, if not employes; therefore some of the statements Mr. Crane has made quite correctly might be misinterpreted unless he was understood to be referring specifically to the passenger-car field. For example, the Chrysler company deserves the distinction of being a pioneer of valve-seat inserts only so far as the passenger-car is concerned.

Also, from Mr. Crane's discussion of the origin of floating power, his definition seems to be an engine with a flexible torque arm, but I thought floating power meant an engine supported in rubber biscuits of some kind. I understand that some of the new productions of the company that invented that term are minus the torque arm. If floating power means the use of the torque arm, then the old Maxwell, the progenitor of the present Plymouth, deserves credit for pioneering. If it means rubber suspension, you must look outside of the passenger-car industry for its invention.

Mr. Crane:—I can describe it this way: The Plymouth

[9]See S.A.E. Journal, February, 1932, p. 57.

[10]M.S.A.E.—President, Engineering Development & Associates, Inc., Plainfield, N. J.

[11]M.S.A.E.—Sales promotion manager, International Motor Co., Long Island City, N. Y.

four-cylinder engine has a large amount of rubber mounting and a spring torque arm. The six-cylinder is confined to rubber-biscuit mounting. Both the four and the six, as I recollect, had practically all of the pedals, the gearshift lever and the brake pedal mounted on the frame separately from the powerplant. Last year the Chrysler-eight line did not have the gearshift and brake mounted separately from the powerplant. That represented the difference as you went further up the line, from an engine that required and one that did not require cushioning of torque reaction. Where the Oakland company stopped was that it did not feel like spending the money on mounting the gearshift lever and the brake lever on the frame separately from the transmission and therefore had to use an engine mounting sufficiently rigid so the driver could find the ball on the gearshift lever without looking for it.

A. C. Woodbury[12]:—I should like to ask about front-end camshaft drives on extra-high-speed engines as they are developing now. Chains of ½-in. pitch were used almost exclusively at first; now chains of ⅜ and 0.4-in. pitch are used in the higher-speed engines, I think, because the higher speed demands the shorter pitch. Chains are being eliminated from some of the smaller engines. Is that not because of the difficulty created by the higher engine speed and would not some of the problems of high-speed engines be solved if shorter-pitch chains were available that were strong enough to stand the pull?

Mr. Crane:—I do not think that the chain pitch is fixed particularly by the maximum engine speed. However, it is very importantly fixed by the necessity that there shall be no chain period throughout the running range of the engine. We established that originally in the first Pontiac six, with the result that chain life was almost indefinite instead of being distinctly limited. It was astounding, in going through the tests, to find how different chains were in that respect. Certain chains would set up a violent whipping action at certain speeds. The use of harmonic balancers has helped that condition a great deal, but there still is the possibility of that slatting period being set up in the chain. That must be eliminated and the pitch and weight of the chain must be adjusted to that requirement.

J. W. Lord:—What oil consumption can we expect at the higher speeds, say in an engine that develops a speed of around 80 m.p.h.?

Mr. Crane:—Apparently we have not yet found any good way of reducing the oil consumption at very high speeds without reducing it more or less throughout the speed range. Some engines have a noticeable tendency to run almost too dry below 30 m.p.h. on high gear because of the effort to get reasonable oil consumption at 60 m.p.h. and higher. It is very difficult to get moderate oil consumption without a good quality of workmanship. Perhaps I should have mentioned that also in regard to multicylinder engines; the oil consumption is affected about as much by the straightness, circularity and parallelism of the cylinder bores, the accuracy of size and fit of the pistons and accuracy of manufacture of the piston-rings as by anything else.

I have always been astounded by the microscopic variations that will produce changes of 200 to 300 per cent in oil consumption; and the burden of preventing that must be borne by the shop. We engineers have not found any way to allow running an engine with bad cylinder bores and badly fitting pistons at high speeds without excessive oil consumption or else running so dry as to get very rapid wear of both pistons and rings as well as on cylinder bores.

O. P. Liebreich[13]:—Mr. Crane's statements in connection with top speeds of 70 m.p.h. or more, with common cruising speeds of 40 to 50 m.p.h., and the engine power gained in changing the Buick muffler, lead me to ask a few questions:

What was the approximate increase in engine power when using the new muffler and the resultant gain in top speed of the old-model car with the same engine?

Since the top speeds of stock engines are now approaching 4000 r.p.m. and the horsepower consumption of the cooling fan varies approximately as the cube of the speed, it seems that the power consumption of automotive cooling fans at high car speeds is worth looking into, especially in view of all the work being done in streamlining to improve high-speed car performance.

Have any tests been made to determine the power consumption of the fan at high speeds?

Do you think there would be any appreciable increase in the maximum car speed with the fan belt removed?

Would the air impact and natural draft at speeds over 30 m.p.h. in direct drive provide adequate cooling?

Would there be any advantage or improved car performance in using a fan that cut out at high speeds or was thermostatically controlled to provide sufficient cooling in proportion to engine-coolant temperature independent of car or engine speed, so that power is consumed only as and when required by the cooling system?

Is it not possible that such a thermostatically controlled fan would reduce the warming-up period in cold weather and tend to maintain a more uniform running temperature in addition to improving high-gear performance?

Mr. Crane:—I have not available the figures as to the increase in Buick horsepower but think it was about 8 or 10 per cent.

There is no doubt that the power required to drive the cooling fan is a most important problem at the present time. As a matter of fact it has always been a problem because of the characteristics of the conventional type of fan. In the old days, however, the fan was usually driven by a separate belt, frequently of the flat type, which permitted of slippage at high engine speeds, thus somewhat reducing the required power. This slippage is not desirable with the V-type belt because of objectionable noise.

There is no question that cooling would be a simple problem at high car speeds without the use of a fan, but the radiator layout would have to be made with this end in view. Unfortunately, such a job would not be satisfactory at low car speeds. When a fan job is made efficient for idling and low car speeds, it is often necessary also to have the help of the fan at high car speeds.

The proposal to make use of a thermostatically controlled fan is interesting, but I cannot comment on it without knowing more about the details of operation. It sounds like a rather difficult mechanical problem, in view of the fact that some fans require 10 to 15 hp. to drive them at top speed.

[12]M.S.A.E.—Consulting automoitve and power-transmission engineer, Bellerose, N. Y.

[13]M.S.A.E.—Chief research engineer, Automotive Royalties Corp., Inc., New York City.

RESEARCH . . . AS I SEE IT

By H. L. HORNING

We live in a world of contemporaneous ancestors; only a few men, and even these only for a short moment, think straight, constructively and creatively, according to H. L. Horning, Past-President of the Society, a member of three fuel-research committees and an internationally recognized authority on research, a subject which he handles in a vivid and attention-holding way.

Three methods by which people come to a conclusion are listed as the deductive, which was the method of the Greeks; the religious, or mystical; and the inductive, or research, which is the modern scientific way. Regarding the last the author says:

The inductive method results from a state of mind; research is a method of inquiry and a way of thinking.

Research has for its object merely to glean that essential element in any situation which will be useful to the attainment of any given purpose.

Research is largely a process of turning things upside down and sideways, looking at them on the inside and in the most unaccustomed ways.

Most business failures are caused by someone not being research-minded.

Mr. Horning goes on to discuss many aspects of the subject and illustrates some of his points with examples from personal experience. Engineering-college professors and industrial research men who took part in the discussion agree with the author's exposition of the subject and make interesting comments from their own experiences.

THREE WAYS in which people may come to a conclusion are:

(1) The deductive method
(2) Religious or mystical thought
(3) The inductive, or research, method.

The first was the system of the Greeks, who probably were the greatest thinkers of all time. They had no limited precedent on which they had to base their conclusions, and this was why they accomplished so much. Their method yielded fair results when they dealt with subjects like politics and philosophy, which they observed and discussed with distinction. Aristotle failed when it came to physics and like subjects, because actual experimental examination was not regarded as a very high-class occupation. Except for a few scientific minds, by far the most common habit of mind has been to accept an authority for some dogma, illusion or vision. Religious tenets, taboos, illusions, delusions and superstitious beliefs still dominate the thoughts of men. Opinions, not facts, occupy most of our thought. The average man decides nearly all questions on an emotional basis. This is the world of the mystic, who believes that the wealth of knowledge and hope lies within himself and his own personal God; in fact, this is the particular state of mind that has created most of the gods.

Every race has had its religion, but we live under the influence of the Christian Epic, a story based on the inspiration of the Bible; and the interpretation of it is a marvelous story of great dramatic and moral value; but, no matter what its pertinent conclusions and tenets, it is based on facts, many of which can never be proved but must be believed to be of value. This way of thinking, or rather believing, always existed and, perhaps so far as our race is concerned, always will exist. With the exceptions of Aristotle, Archimedes, Copernicus, the Egyptian and Arabian mathematicians, Galileo, Kepler, Descartes and Leonardo da Vinci, this mystical way of thinking largely dominated the minds of the ancients. Beginning with the 17th century, Francis Bacon raised his voice against this muddled way and our era of scientific thought began.

Still Living in the Stone Age

We live in a world of contemporaneous ancestors. All about us we find men who think and react in the manner of our distant forefathers. In places in Spain, Ireland, Russia, Asia, North and South America and in the City of New York, are living some men of the Stone Age, who think in taboos and beliefs, believe in authorities, fortune tellers, astrology and the like, and who belong no more to this age than do the bones of men we find in clay 100 ft. below the earth's surface. Furthermore, in the world in which you and I live, the coat we call culture and civilization is so thin in 99 per cent of the men that only a war, street fight, fit of jealousy, call of charity or fair dealing is necessary to crack the layer wide open and expose the primitive man beneath. Never forget that most of us are savages; this explains so many things and saves one so many disappointments; it is the reason that racketeering, political graft and war can exist. The point I make is that only a few men, and even these only for a short moment, think straight, constructively and creatively, even in the highly civilized societies found in such modern countries as France, Germany, England, Sweden and America.

The inductive method results from a state of mind which I shall attempt to define. Research, which is a method of inquiry and a way of thinking, has steadily grown from the 17th to the 20th centuries. The strides it has made, its discoveries and inventions have progressed at such a rate that they can hardly be assimilated by our social, economic and political systems.

Research Defined

I must accentuate how infinitesimal our knowledge is on any subject, how useless most knowledge is most of the time and how useful it sometimes may be. Research has for its object, not to corral all knowledge, but merely to glean that

[This paper was presented at a meeting of the Metropolitan Section. The author is a Past-President of the Society and president and general manager, Waukesha Motor Co., Waukesha, Wis.]

essential element in any situation which will be useful to the attainment of a given purpose.

When I was a boy of 12 my curiosity in mathematics was satisfied for one whole summer by lying on my back in our attic reading the issues of *The Iron Age* for the 10 previous years. In those days, the journal published a discussion of geometrical problems every week, and my memory retains just one impression from all that reading; it is that there must be at least 1,000,000 ways of making an ellipse with a pair of compasses and a straight-edge, yet there is only one fundamental way. If all these ways were known and someone started to find the fundamental way, and found it, that would be research.

Research is a system of reviewing all the facts on a subject for the purpose of separating the essential from the non-essential. It is the quest of the pertinent.

Psychologists tell us that the growth of thought has four steps:

(1) Gathering the facts
(2) Arranging them in some systematic order
(3) Analyzing the system of facts
(4) Applying the conclusions

If we are looking for an analytical definition of research, we need to go no further. Research is just straight, systematic thinking. We may clarify by saying that research is just common sense gone "high-brow."

While the four steps in the growth of a thought constitute the natural divisions in research, they also may conveniently be described as the four stumbling-blocks of research. By far the greatest amount of research is lost because too much is taken for granted in starting to gather the facts. Most men go about research ill prepared, which means that they do not use common sense. Thinking is the rarest and most difficult act of the human mind. When most men have a constructive thought, their faces light up and they become so excited and exhausted that they are unfit for thought for another year or so.

H. L. Horning

Habit usually makes a man approach a subject from the same old viewpoint and he thus loses perspective. The kind of facts needed, their careful selection and the range of facts to be considered require the finest intuition and intelligence. Often so little is known that every method must be tried. This is the Edison way and may be the only approach left. Try everything, observe results, then follow the clues.

Research is largely a process of turning things upside down and sideways, looking at them on the inside and in the most unaccustomed ways. The man who said that life is one grand illusion probably made plain the main reason why we need research at all. Research is not a system of study peculiar to engineering or science, but applies to the most common pursuits of life. In business it consists in taking an inventory every year to see what one has (that's getting the facts), what can be done with some articles (that's arranging the facts), what is worth keeping and what can be junked (that's analysis), and, then, when we act, we have completed the cycle; all the four steps have been observed. This is research in its commonest form.

Why Business Failures Occur

Most business failures are caused by someone not being research-minded; first, because the organization hasn't the facts available about the business; second, it doesn't know how to organize the facts; third, it doesn't know how to draw conclusions from these facts; and, fourth, it hasn't the ability and courage to act on the conclusions.

Looking back over my life, I can remember only one thought which, because of its complete development and excellence, deserves the distinction of being called of the first order of intelligence; that is to say, a thought which passed through the four steps of gathering facts, arranging and analyzing them and then finally the adoption. As a development it was fine, but it remains to be seen if it is a great conception. Now, measuring up the acts of stupidity, I can think of at least a dozen major failures to think straight through to action. That's a bad ratio, but, in reality, the ratio must be even greater. However, so very potent is the value of an idea that I have survived at least up to tonight. So rare are thinking, intelligence, the research mind and the scientific viewpoint that only a few men once in a lifetime give birth to an idea. Such is the stupidity in which we wallow.

Research is intelligent selection and a pathfinder through a forest of facts. Two of the foremost teachers of music in Europe spent some time trying to prove to me that technique is not facile rendition, but, rather, the easiest way of doing a thing. They were right; and so, in the larger sense, research is a technique, or the way to find the easiest way. Research is a fine art which consists in handling a tremendous number of facts, with intuition and intelligence as the sieve through which the unessential facts pass and only the useful ones are caught.

Art is the trick of rendering a conception clearly defined against an ever-fading background of unessentials. Research is the art of thinking straight through to the useful end and rendering a clean-cut conception.

Facts are truths with many coverings of illusions; they are like the layers on pearls. The grain of sand at the core is the truth, irritating, unwelcome and objectionable to the oyster, yet, to the pearl, the central truth, the cause of its existence. Research is the way by which the truth is found by removing layer after layer.

The truth about anything may never be known to man; we can only approach nearer to it. Newton's laws served for 300 years. They were so near the truth that only a revolutionary change in the conception of time, space and energy made possible the rewriting of them. They, or their successors, always will be subject to modification; there always is another approximation.

Value of Indirect Results of Research

In starting a research, certain ends always are in view. The direct results are the primary consideration, and that which justifies the appropriations of time and expenditure is the value of these. The most important factors, however, to which your attention is called are the indirect results, the collateral discoveries, influences or by-products. In a majority of cases they are of equal importance to, and in many cases of greater importance than, the primary objectives.

Columbus was a great research man. When, acting upon the inspiration with which Marco Polo inflamed his imagination and upon the theory of a spherical earth, he started out to find the East Indies for their spices he discovered a new world, whose continents and gold were of vastly greater importance than the East Indian spices. When Röentgen discovered the X-ray, it was a by-product of another quest, and this has led to the discovery of radium, the better understanding of matter, destroyed the atomic theory and substituted the speculative realm of electrons, protons, photons and neutrons, explained the photoelectric phenomena and revealed the strongest assumptions on which the quantum theory rests. It cast light on the mechanism of chemical reactions and physical causes, and, in the end, made chemistry, physics, biology and all related sciences one and inseparable and culminated in the supreme conception of our physical world in the Einstein theory.

One night I had occasion to find my way alone to the far end of our plant, consisting of five buildings; a distance of 1000 ft., criss-crossed with aisles and filled with machinery. I had but two matches and a vague idea of where the aisles and the first lights were. However, I found my way to the end without acquiring a skinned shin or falling over things. When I consider what had been done, it seems to me that all this vast and glorious universe in which we live is only an heroic replica of that dark shop, and that the kind of reasoning which led me to my destination was the same that leads all research. First, I had some conception of the plan of the shop; second, I had two matches (one blew out and I had only one left, analogous to the case in research when one has only one clue left on which to work); third, I knew that lights were regularly distributed and fitted with lighting cords (this is the atomic table of the physicist) and, if I could get to the first, it would light the way to the next and so on to the end, and so it happened.

This, to me, is a perfect analogy of the mechanism by which research, starting with a few facts, spreads, reveals and clarifies, and gives new visions and facts on its way and pays in many happy results. Many places in the shop would have been very difficult to penetrate, for there the lights were not controlled by cords but were on a general circuit, and, even after finding the switchboards, there were so many of these circuits that each would have to be tried to light a particular section. Here again we have the process of research in its primary aspects, for, in the last resort, we must try everything. The measure of intelligence is the way we jump the process of trying every way by reasoning out the one way to an end. Men like Kettering, Midgley and Boyd, who fight through to a result, are the perfect examples of our modern research men. To stumble onto a valuable fact is one thing; that's keen discovery; but it's another thing to fight your way through to results, using every trick of the mind or intuition to get there.

Impediments to Research

Experience has taught that several peculiar things happen during every research project, and one will be sure to run into them. They are

(1) A general hesitation in getting under way. This is the period of gathering facts and corresponds to the homing pigeon's circular flights of orientation.
(2) The tendency to go off on a tangent or become interested in a by-product of the research. To keep the research train on the track is always difficult.
(3) The tendency to delay the finish. Bringing a research problem to a conclusion seems to be the most difficult part of the task, and the greatest value of research is lost at this time.
(4) The psychological collapse when the thing is done. Every one loses interest in it and a great delay occurs in following through to the application of an idea.
(5) The skepticism of the practical man toward the results of a research.
(6) The usual difficulty in getting the market and the world in general to adopt the results of research.

All of these are mental-inertia phenomena of psychology.

Some Distinctions and Technique

Some common misunderstanding exists as to what research is; for most research, as discussed in our magazines and trade papers—in fact, that which is proclaimed in the loudest voices—is really industrial development. I like to make the distinction as follows:

(1) Pure research is the effort to ascertain facts regarding any subject, with no specific application in view and for the sake of the knowledge itself.
(2) Applied research is the effort to find the best way of meeting specific problems.
(3) Industrial development is an effort to apply the results of pure and applied research to a specific problem for useful gain.

While all research is interesting, such research as is now being carried on to learn why fish go in schools, the causes of their migrations and the influence of sun radiations on the fish food is, to my mind, the best example of pure research. Ascertaining how to take advantage of the results of the research for the purpose of making fishing safer in all weather is applied research. And learning how to keep the fish supply available for a greater number of months and utilizing supplies of less known fish to maintain the continuous supply is industrial development.

Competition drives most industries to try to understand their individual problems, and it has been found that companies which carry on research have great stability. Just to have a research department does not mean that a company will be stable, for this depends upon the quality of research, the guidance and the question whether the market will like the product.

Not many years ago a company in the automotive industry came to a dead center. The president became aware that something called "research" was sadly missing, and that was why competitive units in the industry were prospering. He ordered a proving ground and a laboratory. When plans for the laboratory equipment were presented to him for approval, he glanced at the amount of the appropriation, swept it aside with a grand gesture, and said, "Double it." His idea that doubling the laboratory equipment would double the value of the laboratory product is really one of the great misconceptions. I believe, after trying both ways, with little and with much equipment, that the value of the work done varies inversely with the value of the equipment. This should not be so, but it accentuates the fact that the mind is the thing and the apparatus just an accessory.

American laboratories are overgrown. We Americans seem to lose sight of the problem in the maze of our equipment. It is a great delight to see many foreign laboratories and to observe the results they get from their meager apparatus. Results depend more upon mental equipment than they do on physical apparatus. Nothing is so rare as a man with a research mind.

Brains, the First Essential

I cannot pass without emphasizing this characteristic called brains. Once we were helping a licensee to develop a lighting plant. The gasoline was contained in the base of the engine. When the tank was full, the engine worked well, because the lift was slight. When the tank was empty, the mixture was lean and the engine worked badly, or sometimes not at all. One of our engineers considered the problem. His mind went back to his days at the Massachusetts Institute of Technology and he wrote down a formula, studied it and said, "All you need is a tube 1½ in. long, which you attach here and there, then the engine will never know whether the tank is full or empty." We tried it, and it worked. When we tried to patent the idea, we found that some of the best minds in the Society had missed the solution by two holes. As quickly as this all happened, it still was research, for that engineer went through the same processes of mind as if a year of research had been spent on it.

The Forgotten Man

We have in our shop a man who has been with us since the beginning, 26 years ago. He is a free-lance. He reports to our production manager and the chief inspector. He is responsible only to me. He wears no man's yoke, but his allegiance is only to our best interest and his conscience is his only critic. No one ever sings his praises as a research man. His picture never appears in the S.A.E. Journal with the prima donnas who visit us. No one asks his title or questions him. He is the super-mechanic. When things go wrong and all of our high-brow specialists muff the answer, he is there with the goods. Eventually, he brings home the bacon. I have watched him work, and I find, as he does his stuff, that where he beats us all is in the first step, which I pointed out in the beginning. He gets his facts. He takes no one's word for anything. He observes, and his eye is better than the brains of 20 research men. He gets the essential fact. His other trick is that he comes through with the analysis and then applies his remedy, and it works. You can't beat that for research, yet no one calls it that high-brow name. When we are all driven to the wall with a problem, I always like to meet him in the shop. He looks for my encouragement, and together we can dope it out. Don't overlook a man of this kind in your shop. He will surprise you.

We have another man who was the first to notice that a washer resting on the flat cylinder-head of an L-head engine jumped every time the engine detonated. This led to Midgley's indicator and Dr. Dickinson's calculation on the pressure of the flame front; the rate of pressure rise helped to form our theories of detonation and to build our business from 25 to 300 engines a day in one model, just because we had learned by research how to soften the effect of a rapidly rising pressure curve.

Don't depend too much upon high-brow scientists. Keep your ear open to the man in the shop and on the road. The answer to any research problem isn't particular where it lurks; it often hides under the dirtiest hats.

Research Problems Can Be Divided

Someone has said that you can't hurry a research any more than you can hatch the eggs ahead of time by using two hens. There is plenty of truth in that, but, if the problem is big enough, it seemingly can be split into units of conquest and each unit farmed out to one man, with management helping them all toward an end. You will find a lot of difference between men. Some seem just as intelligent to talk with as others, but, when you get them down to brass tacks in a research problem, you will find that one gets ten times as far in a given time as the rest. In the matter of intelligence you must rate them exponentially. One man may have a value of 10, another may seem 3 times as bright but really is 1000 times as bright; it's 10^3 for him.

During the World War we had trouble with the main bearings in the Liberty truck engine. Some German was throwing lead into the babbitt, and the bearings had bubbles. We could not determine this by inspection; bubbles showed up after the test was completed. Bearings had to be thrown away and others put in, which was a great loss. I put a man to work. He made a specific-gravity scale and, after testing about 100 bearings, we found that we had two piles. The sound ones in one pile were easy to distinguish after we had brought a great many together. Likewise, the bearings that had blow-holes could easily be distinguished after we had a great number to look at. After weighing the first 100, a tedious operation, we did not have to weigh any more. Our inspector won a hat and coat and a pair of shoes from the manufacturer, because he picked 10 bearings out of 100 and every one showed up bad. I would point out that, in research, it is important to work your picture so that you have every factor brought to one point, for then you can distinguish the vital differences. That is the secret of all art.

Research, in its essence, is hunting. The first research man was a hunter who, instead of being discouraged because he found no game the first or the 20th time in going through a wood, stalked through in another way. A well-known rule in hunting is:

Do not look too intently for the object of the hunt. Let the eyes be at ease and rove carelessly and slowly and not too sharply over the woods. Thus you are much more likely to cover the ground more thoroughly and see your hiding game than by giving the attention to one object. Don't stare—browse!

This applies to the initial stages of research when facts are being gathered. The time to stare is when you have the facts.

In research a lot of time is lost by not anticipating require-

ments for equipment and not planning ahead and keeping equipment coming before the research worker needs it. Research can be scheduled; perhaps not as manufacturing is scheduled, but it may save just as much time. Research drags and drags because it is not planned. Some persons wonder how we get things done so quickly in our research laboratory. It is by planning ahead; by organization; by cooperation and foresight. Someone has brains. Someone has eyes. Others have ears. Others have the sense of touch and smell and together they get along rather fast.

I find that lack of faith in a certain piece of research slows it up more than anything else, except lack of planning.

Cooperative Research Is Profitable

MOST research involves a narrow interest and the problem of only one individual. Some larger problems concern a company and others can be solved for an entire industry only by common research. Because the entire industry has a community of interest in the subject, it would be of little value if one company could solve the problem, and, even so, the combined brains and resources in ideas usually are required to solve some problems. Here it pays to get together; and, finally, for the benefit of all, it may be profitable for two or more industries or institutions to pool their resources for the solution of some very general and fundamental problem.

Many notable achievements have been accomplished in the last few years by the cooperation of entire industries on research problems of wide interest. Such mutual problems of the automotive and the petroleum industries, the solution of which would otherwise have been delayed for years, have been solved by consent and cooperation. For example, cooperation of the automotive industry represented by the Society of Automotive Engineers, the American Petroleum Institute and the Bureau of Standards has produced a notable piece of research in the field of volatility of gasoline and has enabled the oil companies to increase their yield and at the same time give vastly better fuel. The value to the public of increased production and decline in cost can be measured only in hundreds of millions of dollars in the few years it has been in effect. Vapor lock and other problems also have been effectively solved at an insignificant cost.

The value of the work of the Bureau of Standards, because of the high character of its men, their keen minds and their neutral position, points out the last and most necessary element in large cooperative efforts. Likewise it requires a man like C. B. Veal, a Judge Landis in the situation, to keep men forever forgetting themselves and their personal interests so that a true solution can be obtained.

Finally, the more I learn about evolution, biology, psychology, business, industry and human affairs, the greater is my conviction that research is our most effective tool for refining the truth out of the chaos of ignorance, and therefore it should make life easier and happier. It is a creative process. Happiness is the reaction to a creative process in which we reproduce ourselves with variations in body or in some material or spiritual form.

THE DISCUSSION

DR. HARVEY DAVIS[1]:—Mr. Horning said absolutely nothing with which I am not glad to agree. I like his advice about questioning everything at least once. Some years ago Josh Billings said, "It is fine to know a lot of things, especially if some of them are so."

Mr. Horning also said something about pure research. I want to mention an example of research of that kind. A young man who got a doctor's degree in the University of Kansas on a paper that had been accumulating for some years, reached a climax of presentation and said: "Gentlemen, I am sorry to take up the time of this meeting, at a time of stress like this, but I do want to get it off my chest and then we will all get to work and do what we can to win the war." That boy apologized for determining the character of certain rare gases in gas wells in Kansas on which the United States Government had spent $3,000,000 for research. As a result of pure research the cost of helium came down from $60,000 a cubic foot to about $60 per 1000 cu. ft., which is doing fairly well for pure research.

Mr. Horning's mention of the disadvantages of too much apparatus agrees with certain of my experiences. The only disagreement I ever had with Professor Sabin, my chief at Harvard University, was when he said, "You must have a good vibration microscope. They cost only $300." I said, "I think I can do better work with a package of cambric needles and some smoked glass." And we never bought the vibration microscope.

A personal friend of mine, who was in the automobile business for many years, once won a prize of $5 offered by a New York City newspaper for being the first man to drive an automobile around Central Park without a forced stop. It took him six weeks to do it. So you can see what research has done in that one field.

Culture Demands Research Spirit

A lot of business failures have been due to the fact that the executive in charge did not have the research spirit. The spirit of science has been seeping into so many branches not ordinarily called science at all—into industry, economics, sociology and even law and politics, that is, government—that it is impossible in this day and generation for a man to be really cultured unless his education is shot through and through with this research spirit. President Lowell of Harvard once said, "The science of research is asking the question in the first place." At least three-quarters of the successful conclusion of any piece of research is accomplished by the man who asks the right question, the student does the other quarter, and then we give the degree to the student, not the professor.

In talking of research, particularly research in industry, I think we should distinguish three different things. A good deal of routine work going on, such as testing raw materials, is not research, although it has been called that. The second kind of work, which I judge is the backbone of research, is development, the drawing out of new methods, developing new devices and new products, and searching for certain things for certain purposes. That is of tremendous importance. It is the work from which dividends are most likely to come in the immediate future and fairly regularly. It is the kind of research which discloses the fundamental purpose of things. I am inclined to think that industries should be

[1] President, Stevens Institute of Technology, Hoboken, N. J.

doing more of that, as their contribution to the general scientific picture, than they have been doing. Applied development work cannot go on indefinitely without a new crop of ideas to work on, and we cannot depend upon universities to produce industrial ideas on which to work. As a sort of life insurance for their own good, many companies should pay more attention to fundamental research than they have done in the past.

Types of Research in Schools

PROF. L. C. LICHTY[2]:—I think that Mr. Horning's attitude on research is ideal. Industrial research usually is done for profit, immediate or future. A few concerns, I believe, in good times consider it a luxury which they can discard in poor times. The school, however, is designed to train students to think and is not primarily for research, but this is an excellent means for developing the process of thinking. The student who launches into a research problem lines it up and carries it out to a successful conclusion, seems to have improved his power of thinking. Some time ago someone analyzed the types of research being conducted in schools as

(1) Actual research for fundamentals
(2) Study and solution of industrial problems
(3) Routine testing
(4) Semi-scientific puttering

Considerable care should be exercised to be sure that a project is worth while and that it does not fall into the fourth class. The person undertaking it should be capable, thoroughly sold on the idea and interested in it. That is one of the advantages we have in school; we are not forced to conduct research in which we are not interested.

Care in conducting research is important. Two projects may look exactly alike on paper but care must be taken in carrying out the work so that correct data are obtained and correct conclusions are drawn. Cooperation of the schools with research in industry is most beneficial. It keeps the instructors informed regarding problems and methods in industry, advances their knowledge and should make them better teachers. While research is essential to the life of an industrial concern, I think that it also determines the kind of life the school is going to lead.

Comparative Data on Industrial Research

DR. DAVIS:—Some data were obtained as to research activity in 1931 and 1929 for comparison. It was discovered that, of several hundred firms, more than 51 per cent were spending more money in 1931 than in 1929 and that 70 per cent were spending as much or more in 1931 as in 1929 notwithstanding the fact that prices had gone down and the intensity of work had gone up. Of the large organizations, 90 or 95 per cent were having more work done in the bad year than in the boom year; and 91 per cent of these firms were spending as much, or a larger percentage of their total expenditures, on research in 1931 as in 1929.

Also, the character of research shifted between those two years. In 1929 about 31 per cent of the companies reported that the chief object was to reduce production costs. In 1931, only 19 per cent were primarily interested in reducing production costs. In 1929 only about 35 per cent were primarily interested in new uses or new products, whereas last year 43½ per cent were so interested.

[2] M.S.A.E.—Associate professor of mechanical engineering, Yale University, New Haven, Conn.
[3] Dean of engineering, Columbia University, New York City.
[4] Petters, Ltd., London, England.

The National Research Council feels that industrial research is a forestalling weapon in the hands of management which can be used under some circumstances for one objective and under other circumstances for another. Somebody is wanted to invent something that will produce new business and new construction to produce that business.

Note Both Positive and Negative Results

J. W. BARBER[3]:—I recommend the reading of Faraday's book, *Experimental Researches*, and advise observing how carefully Faraday noted down not only his positive results but also his negative results; not only how carefully he progressed in thinking step by step toward the goal for which he was headed but in that process carried each experiment one step further and noted down each by-product for possible future reference. He was continually noting on the side with a big mark, "This is something to come back to." Those who take up research can learn a great deal from that lesson.

The by-product subject is very interesting to me. Some time ago I was carrying on research on the effect of illumination in industry and we needed carefully controlled conditions. We could measure the laboratory production of the workmen on the basis of their ability to see. We tried to put the system into a factory for a test and there we ran into the human factor, which is one of the biggest variables. As a result, we determined upon the semi-laboratory type and prepared two rooms as exactly alike as we could. In one the light was kept constant and in the other it was changed. At that time I was in Boston and this research was being carried on in Chicago. One morning the research assistant called me by long-distance telephone and said that the production of the control group had jumped 10 per cent over the average level that had been maintained for six months and that the production of the other group had decreased correspondingly without any change in the light. So I went to the factory in Chicago and my first impression when I stepped inside of the control room was that something was different. I said, "This desk was not here before, was it?" They said, "No, it was in the other room. We had moved the desk by accident and every week production changed 10 per cent both ways."

That was a sad thing for the piece of research on which we were engaged, but the company executives said that if the change of a desk could possibly affect production 10 per cent they would better look into the matter. So we continued with another group, keeping the lighting exactly the same. Before six months had passed, that one observation that came solely by chance was netting the company $5,000 a month, simply through the effect of changing supervision. Then the company set up a school for teaching gang bosses how to supervise, and out of it came another piece of research that netted it about the same amount per month.

By-Products of Greatest Value

SIR ERNEST PETTERS[4]:—We have to take away with us tonight the thought that nothing is so important as by-products. I occupy in England almost the identical position that Mr. Horning occupies in the United States. We have had great pleasure in exchanging visits during the present year and I have got to know him, his problem of the development of internal-combustion engines and his difficulties, and every time he tells me something it is of importance in experience,

such as how he failed to follow the unexpected thing which had happened and lost the opportunity of arriving at some great result. We all have had the experience, and the lesson, I think, is this: to take the greatest possible notice of anything unexpected that happens in your research work and in your line of development. Something very simple may lead into something very great. For example, the development of rustless steel, which has so altered mechanical engineering practice in the last few years, was more or less accidental. We were trying to find some metal that would resist the corrosive action of the acids of high explosives which were wearing out the guns very rapidly during the World War, and out of that research we got what in England we call stainless steel, with all its developments.

Processes of Successful Research Men

Frank C. Mock[5]:—Engineering research has been particularly prominent in automotive history. The record shows a number of instances of individual companies, manufacturers of cars or accessories, having for certain periods forged ahead of all competition in their line, solely because of the achievement of one or a few of their men in research; and, similarly, when their research policy of personnel changed, they speedily lost their eminence. Just what these few men had which enabled them to progress so far is difficult to define; those I have known have been curiously alike in possessing a simple directness of thought, without too much regard for precedent or textbooks, and looking at nature as does an intelligent, inquisitive child. I can say, however, that all of these men seem to have employed the same general method: first, to experiment, observing keenly; then to analyze results and reason rationally up to another experiment; and so on, the experiment preceding and directing the thought.

Rather peculiarly, this process does not seem to come easily to the average human mind. Apparently, the men of 2000 years ago were as keen in reasoning as those of today; yet, if the curve of scientific progress be plotted, it will be seen to run almost horizontal for many centuries, beginning to rise only about 200 years ago. It is significant that, in the earlier period, the wise man was pictured as wearing a white robe, looking off into space, rapt in abstract thought; but from Faraday on a change took place; the scientist became an observer, an experimenter, and soiled his clothes and his hands. Such intimacy with nature's processes seems necessary in order that the mind may be released from preconceived notions and prejudices and yet be able to build upon the knowledge and experience of the past.

Social Economic Problem for Engineers

The thought comes to me that all this has a particular bearing upon the greater-than-engineering problems; that is, the economic problems of today. Specialization in occupation, mass production, the tremendous utilization of new sources of energy and power for the service of mankind, have resulted in a new form of civilization which, however admirable otherwise, seems to prove itself *essentially unstable* in its adaptation to basic human needs. As we have experienced its development in the last 80 years, this instability has become more pronounced and the condition has spread from the countries first highly industrialized to those more recently changed. This is a new problem to the human race, and it is a disturbing thought to me that the democratic form of government, with opposing political parties, is particularly handicapped in applying the successful methods of research to its solution. A continued program of experimental trial, then analysis, then a second experiment developed rationally from the first, and so on, is almost impossible; indeed, the word "experiment" seems likely to be a reproach in our politics for some time to come.

Imagine two men, A and B, engaged in a certain research problem in one of our large companies and responsible directly to the board of directors. A makes an experimental device and tests it, with satisfactory results as regards certain functions but finds changes necessary in other details. B, who has been watching over A's shoulder, goes immediately before the executive committee, elaborates on A's lack of success, gets A discharged, and then starts work on an entirely different machine of his own. A, who is accustomed to all of this, as the company has been run this way for years, hangs around the place until B gets his machine along to its first test, waits for the small defects that are customary and inevitable in a first trial, reports them to the board of directors, and gets B discharged and himself reappointed. However, he is not able to take up his previous experiments where he left off, because they have been discredited by B's criticism, so he has to begin another line of attack. Thus continues an inevitable repetition of change in management and program. This, with A and B as the political parties and the board of directors as our electorate, is a true picture of the manner in which we have to make progress in government today. It seems to me that we, as engineers, can render no greater service to our Country than to obtain prestige and dignity in the popular mind for the idea of continuous orderly experimentation in government. Otherwise our progress must remain halting and difficult and comparable to the advance of science in the Middle Ages.

Maurice Walter[6]:—The thought occurs to me that possibly we have the word "research" from the French "*recherche*," which, translated literally, means to look for again, which is more expressive of the thought than the word "research" as currently used.

I am worried about this super-cast-iron that Mr. Horning's company has developed. I think it sounds too perfect, and as soon as I have time I am going to try to find what is wrong with this iron.

Anything Is Possible within Natural Laws

E. R. Hewitt[7]:—I think that the most important point of view to be obtained is, first, that you can do anything you want to do provided it is within natural laws. Second, the hardest thing is to find out what you are trying to do; and one of the most important qualities is that of absorption. I will give two examples, one negative and one positive.

About 1895 my father was doing some photographic work in conjunction with Mr. Tesla, who was experimenting with Zeisler tubes. Photographs were made using tubes that Tesla had made and was going to develop further. The photographs came out very badly. A few months later the discovery of radium and X-rays was announced. Digging out his negatives, my father found on those plates a picture of the metal screws of the camera. Tesla had missed X-rays through lack of absorption and did not get what he was looking for.

[5] M.S.A.E.—Research engineer, Bendix Research Corp., East Orange, N. J.

[6] M.S.A.E.—Chief engineer, Walter Motor Truck Co., Inc., Long Island City, N. Y.

[7] A.S.A.E.—Consulting engineer, Mack Trucks, Inc., New York City.

My uncle, Peter Cooper Hewitt, who was making X-ray tubes, for some reason used a mercury electrode. One day he turned on the electric current while he was exhausting the air out of the tube and a flash of light illumined the tube. He thought, "If I can catch that and make it stay there, I shall have a good light." The task took him five years but he did it.

HERBERT CHASE:—I was especially interested in Mr. Horning's mention of cast iron for crankshafts and should like to have him tell us in a little detail about the characteristics of this metal.

MR. HORNING:—Mr. Chase asked for more information about cast iron for crankshafts. We are trying to get a patent covering it and I cannot tell how it is made. It is an alloy. What is wrong with this iron? It costs too much. We already have an engine with it in. One of the difficulties encountered with iron heated to high temperature is that the silicon is passed over from the iron valve-seat to the valve itself.

I feel that I have got more value out of the comments of Dr. Davis, Professor Lichty, Dr. Barber, Sir Ernest, Mr. Mock and Mr. Hewitt than they could possibly get out of my paper. After hearing them, I am reminded of Coolidge's crisp remark about sin: "I am against it." However, I feel I am now for research. The more I hear the more I should like to know about research.

SOME OLD-TIME CAR VIRTUES MISSED

IT is getting along toward the time of year when motor-car manufacturers announce loudly their new models; and perhaps we had better seize the chance to come right out and say what we think of the trend in motor-car design. Are you ready, men?

We think it is terrible. We think motor-car designers have been gradually going crazy. The tendency today is to make a car that is more like a diving-bell than a pleasure vehicle. Things were, in a way, better in 1917. Today the sill of the front window is on a level with the driver's upper teeth. He can't even spit comfortably. The cowl is on a level with his eyebrows, so that he can see ahead only by tying his neck muscles in a fisherman's knot. The windows are so tiny he has to shut one eye and squint through them as you would through gun sights. The top of the steering-wheel is on eye level, designed to cut off 65 per cent of the forward vision. The seats are pitched in a nasty V-shape, to bring on stomach cramps with the least possible delay, and the whole car is built so low to the ground that we wonder why it is not infested with moles. The only way to get through the doors is by crawling through on one's hands and knees.

Getting bitter, are we? Not at all. We have always liked automobiles, as such, and still do. We just do not want them to forget some of their old virtues in the confusion of their new speed. We owned a Pope-Tribune once, and it was not so hot; but we distinctly recall that it was more fun to sit in than the elaborate bundle of nerves that whisks us about today. We owned a Model-T Ford roadster once, and it was not so hot either; but we could hang our left leg out over the side when the day was warm and fine. Have you ever tried to hang your left leg over the side of a modern roadster? You would break every bone in your body. Those old cars had something, something worth remembering and hanging onto. Why do rich old ladies around town hang on grimly to their ancient limousines? It is not the depression, or the style, that makes them do it. It's because the doors are high enough to walk through without getting your hat knocked off, the seats are level enough to sit on without getting indigestion and the windows are big enough for the occupants to see out of.

Come to think of it, those linen dusters were handy things, too! —*The New Yorker.*

MISPLACING THE CENTER OF GRAVITY

WE are going to cars of very low center of gravity on the mistaken idea that they are safer than cars with a higher center of gravity.

When the railroads first built electric locomotives of great power, they were designed with the motors down between the wheels and a great boast was made that in going around curves they could not be upset because the center of gravity was so low. Within a short time after the railroad that tried them out put them on a run, a serious accident occurred. The engineers had forgotten that, with this low center of gravity, a side thrust was created on the flanges of the wheels and on the rails which the rails and flanges were not designed to take. So later electric locomotives had the weight away up in the engineer's cab. When a locomotive of this type goes around a curve, the weight swings to the outside and presses down on the outer rail, so very little thrust results to either spread the rails or break the flanges on the wheels.

The case of the automobile is exactly analogous. If the center of gravity is too low, the thrust on the outer tires is changed on a turn from down pressure to side thrust, which forces a skid on wet pavement or tends to push the tire off the rim on dry pavement. Whether this is serious or not remains to be seen, but at least it is obvious that the center of gravity should not be down between the wheels.

There is also a psychological reason for this. Early automobiles were high from the ground and the riders had a feeling that they were likely to be thrown off. In very low cars one has a feeling that he is likely to be run over, which is also bad psychologically.

For the sense of safety and maximum confidence that one should have in a motor-car, the occupants must be seated so that their eyes are at the same height as when they are walking, as this is the height from the ground to which they are accustomed. This is of surprising importance as regards fatigue in a day's drive to one who is at all nervous in a motorcar, and some persons still are.—From a Summer Meeting paper by William B. Stout, S.A.E. Vice-President, president Stout Engineering Laboratories, Detroit.

INDICATORS *as a Means of Improving* AIRCRAFT-ENGINE PERFORMANCE

Discussion of Ford L. Prescott's Aeronautical Meeting Paper

E. S. Taylor[1] and C. S. Draper[2]:—Mr. Prescott is to be congratulated upon his sampling-valve indicator, which seems to give very reasonable records. In the aeronautical engine laboratory at the Massachusetts Institute of Technology we also have experienced considerable trouble similar to Mr. Prescott's with optical, electrical, sampling-valve and balanced-pressure indicators. We have succeeded in developing an apparatus of the balanced-diaphragm type which has eliminated most of the defects in this type mentioned by Mr. Prescott and at the same time is simple and gives very accurate records.

In cooperation with Dr. H. E. Edgerton and K. J. Germeshausen, of the electrical engineering department at the institute, we have been able to produce a vacuum-tube relay circuit for the balanced-pressure type of indicator which is easy to operate and runs from the 110-volt lighting supply. This relay is arranged so that it produces a spark at the secondary of the spark coil when the diaphragm makes contact. By throwing a switch it can be made to produce a spark when the diaphragm breaks contact. The induction coil is caused to produce its spark by discharging a condenser across its primary terminals through a mercury-filled thyratron tube. This eliminates the objection due to the time required to build up sufficient flux in the induction-coil core.

We found that part of the scattering of points which is noted with the R.A.E. indicator is due to flexibility and play in the indicator-drum driving mechanism, and we have redesigned the recording mechanism so as to reduce this play to the minimum and to simplify the manufacture. A photograph of the indicator recording mechanism is reproduced in Fig. 1. Some spreading of points during the combustion part of the cycle still occurs. However, this allows the maximum and the minimum values of maximum pressure to be determined, and the spread is small enough so that, if desired, an average value can be drawn in with a fair degree of accuracy. When these cards are replotted on a pressure-volume basis, however, the difference in the shape of the card is small whether the maximum or the minimum values are used.

In our work we have found that one of the major difficulties in indicators of all types is that of getting the indicator element into the spark-plug hole of an ordinary cylinder without the use of a long adapter. Consequently, in designing our balanced-pressure diaphragm unit, we have limited its size so that it can be placed in almost any 18-mm. spark-plug hole.

This unit is shown together with an ordinary spark-plug in Fig. 2. This unit, provided with a diaphragm 0.003 in. thick, will stand up for many hours of continuous operation without auxiliary cooling.

Mr. Prescott's objection to the balanced-diaphragm indicator for taking light-spring cards on account of its tendency to shift the zero position a pound or so is well founded for a small-diaphragm unit such as is shown in the photograph. However, a much larger diaphragm with a comparatively long connecting tube may be used for light-spring diagrams without introducing serious error due to pressure waves.

A complete indicator card taken with this instrument is shown in Fig. 3. The vertical dotted line on the record is caused by the ignition spark and is used for getting the correct phase relation of the diagram. The ignition system should be provided with a Neonlight spark protector such as is used on the C.F.R. engine, so that the time of the ignition spark can be measured accurately.

The pressure-volume card shown in Fig. 4 is derived from the pressure-time record shown in Fig. 3. Note the close

Fig. 1—Recording Mechanism Used with M.I.T. Balanced-Diaphragm Engine Indicator.

[The paper was published in the September, 1932, issue of the S. A. E. Journal, p. 361. The author is senior mechanical engineer, powerplant branch, Material Division, Air Corps, Wright Field, Dayton, Ohio, and a member of the Society.]

[1]Assistant professor of aeronautics, Massachusetts Institute of Technology, Cambridge, Mass.

[2]Research associate, department of aeronautical engineering, Massachusetts Institute of Technology, Cambridge, Mass.

FIG. 2—BALANCED-PRESSURE DIAPHRAGM-TYPE INDICATOR UNIT AND CONVENTIONAL SPARK-PLUG FOR 18-MM. HOLE.

agreement between the indicated mean effective pressure as measured by the usual method and as measured from the indicator card. This close agreement is characteristic of indicator cards taken by this method; in fact, it seems possible that friction horsepower can be measured as accurately from the indicator card as from the usual motoring test. About 30 sec. is required to take a complete card with the M.I.T. apparatus.

De Juhasz Corrects Erroneous Impressions

K. J. DE JUHASZ[3]:—Mr. Prescott's survey of high-speed indicators and the account of his extensive first-hand experience with them forms a useful contribution to the literature on this subject. It is particularly satisfying to hear from such an authoritative source the endorsement of the usefulness of indicating tests, especially of the light-spring diagrams, for engine development.

As the De Juhasz indicator was, to my knowledge, the first apparatus actually built incorporating the point-by-point principle, the method having been conceived in 1915 and the first apparatus built in 1920 and 1921, the recognition given by Mr. Prescott to this instrument is gratifying to me. However, I wish to correct some statements in the paper which seem to me to be misleading.

The erroneous impression is given that the interrupter valve should, of necessity, be united to the phase gear, whereas the two can be separated if the local conditions of the engine tested make such an arrangement more convenient. Provision for this has been made in the design, and as early as 1924 I made a complete design for multicylinder engines which incorporated a sturdy phase gear and as many valve elements driven from it as the cylinders to be tested.

The large discrepancy between the actual and the recorded maximum pressures as obtained by Mr. Prescott with the De Juhasz indicator is not borne out by my long experience with the instrument. Of course, owing to its very principle, the point-by-point method cannot be expected to record the highest value of a number of consecutive maximum pressures, but records the median value of these. Perhaps in the particular instance of Mr. Prescott's test, some fault in the set-up, for example, leakage from the indicator side, was responsible for this error, or perhaps lack of sufficient lubrication to re-form the oil-film seal on each stroke of the slide valve. This supposition is supported by Mr. Prescott's remark that, by supplying castor oil, the error was reduced. It is evident that, under the strenuous conditions of indicating high-speed engines, the best results can be obtained only by painstaking care in operating the instrument.

Slide-Valve Interrupter Believed Best

Regarding the poppet-valve interrupter constructed by Mr. Prescott, I still hold the opinion that the slide-valve interrupter, as used in my indicator, is superior to other types for very high speeds, say above 3000 r.p.m., for reasons set forth in my paper[4] read before the Society in 1929. This opinion is substantiated by experience, a De Juhasz indicator identical in design with the one used by the Wright Field engineering division having been used in 1925 on a supercharged racing engine at 6000 r.p.m. with entire success for both strong-spring and weak-spring diagrams. The connecting pipe does not introduce noticeable errors, as is confirmed by Mr. Prescott's experiments, because at high temperatures and pressures the velocity of sound is far greater than the theoretically assumed value of 1200 ft. per sec. Therefore, that the position of the valve should be flush with the combustion-chamber wall is not of outstanding importance, and, in my opinion, this is dearly purchased at the price of an extra hole in the cylinder head.

A simple calculation shows that a poppet-valve type of interrupter is suitable only for comparatively low-speed ranges. Assuming a valve-opening period of 6 deg., a valve lift of 0.01 in. and, furthermore, constant acceleration and deceleration of the valve, the value of acceleration is:

$$a = 0.0133\ n^2 \text{ ft. per sec. per sec.}$$

or

$$a = 0.000415\ n^2 g$$

where g is the acceleration of gravitation. At 1000 r.p.m. the acceleration would have to be 415 times gravity, which is about 8 times as much as is admissible in the valve design of high-speed engines. And this factor increases with the square of the speed.

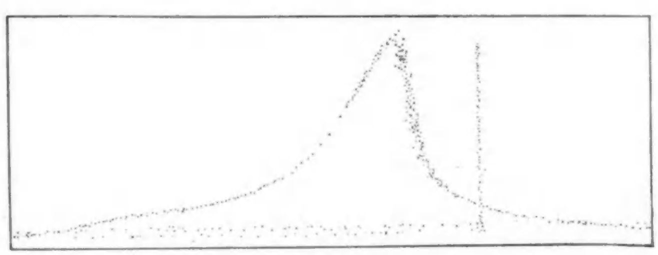


FIG. 3—PRESSURE-CRANK-ANGLE DIAGRAM TAKEN WITH THE M.I.T. INDICATOR.

[3]Assistant professor of engineering research, Pennsylvania State College, State College, Pa.

[4]See *The Automobile Engineer*, August, 1929, p. 303.

This difficulty can be mitigated to some extent by using a masked valve or some similar cross between a poppet and a slide valve. To satisfy eventual needs in the lower-speed-engine field, I have been working for some time on the design of such a positively seating valve, somewhat similar to Mr. Prescott's design but differing from it in constructional details. I am still in doubt, however, whether a real need exists for such a modification, because the cost of my present indicator forms but a small percentage of the total cost of a complete engine-testing stand.

By what measures were these difficulties overcome by the Air Corps engineers? What is the opening period of the Prescott valve expressed in crank degrees? What is the area of the opening? Some of the weak-spring cards show signs of wire-drawing. What make of engine indicator was used for obtaining these?

The phase gear shown in Fig. 10 of the paper appears to be rather smiliar to the De Juhasz type. In what respect does it differ from, or is an improvement upon, this latter unit?

I am sure it would be of interest to many if Mr. Prescott could supplement in these respects the somewhat meager information contained in his paper.

Indicator Cards Essential to Engine Study

Sanford A. Moss[5]:—I am proud to have been concerned with the initial arrangement for the presentation of this paper, because it seems to me to open up a new era in the development of internal-combustion engines. Mr. Prescott, in his title, limits discussion to aircraft engines, but everything given in the paper applies equally well to automotive engines. Indicators of the various types that Mr. Prescott describes have been in use. However, indicator cards, up to now, have not been regarded as an important factor in internal-combustion-engine design. Now that Mr. Prescott's indicator is available, indicator cards, no doubt, will be used more extensively.

Early steam engines were designed very much on the basis on which internal-combustion engines have been designed up to now, with valve timing based principally on trial and error and the effect on the over-all power of the engine, without knowledge of detail. The development of completely satisfactory steam-engine indicators about 1870 or 1880 changed this picture, and indicator cards became important factors in steam-engine design. Mr. Prescott's indicator undoubtedly will lead to a similar situation with internal-combustion-engine design. Indicators are much more necessary with modern internal-combustion engines than with the old steam engines, because of the greatly increased speeds, greatly decreased weights and the greater necessity for maximum power at minimum expense.

A study of the sample indicator cards given by Mr. Prescott shows that merely beginning to open a valve at a given point does not mean that the cylinder pressure knows anything about the existence of the valve. The "steam lead" and "exhaust lead" of the steam-engine nomenclature, or the amounts of valve opening at the ends of the strokes, are important factors, the effect of which can be shown only by indicator cards. Valve-opening diagrams will give some information as to cam shapes that give slow opening, but the effects of cam and shaft torsion, valve springs, passage areas and many similar items give influences that can be investigated only by the indicator card itself. Papers recently published show the increase of supercharged-engine power due to increase of overlap of intake and exhaust-valve opening. However, mere overlap is only one of a number of items.

[5]Engineer, Thomson Research Laboratory, General Electric Co., West Lynn, Mass.

Another important factor that never existed in steam engines is the synchronous vibration of fluid in manifold columns, giving pressure waves, sometimes called "ramming."

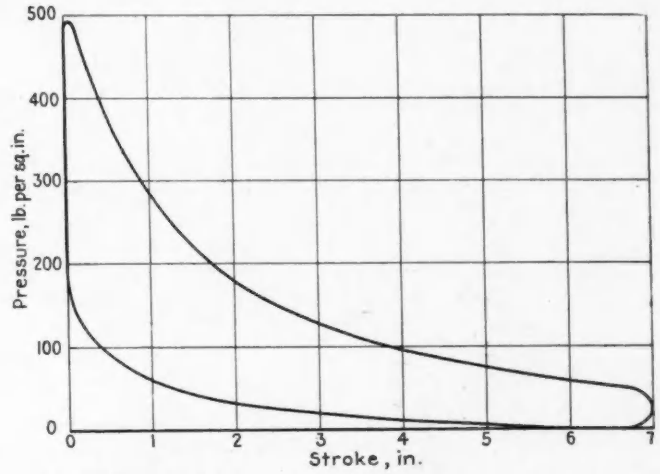


Fig. 4—Pressure-Volume Diagram Replotted from Fig. 3.

N. A. C. A. Engine Compression Ratio	5.0:1
Indicated Mean Effective Pressure, lb. per sq. in.	131
Brake Mean Effective Pressure, lb. per sq. in.	108
Friction Mean Effective Pressure, Motoring Test, lb. per sq. in.	20.5

These pressure waves can exist in either the intake or the exhaust manifold and can serve either to increase or decrease the indicator-card area. Adjustment of the lengths of manifold columns, with indicator cards as a guide, gives an easy means for increasing engine power at or near a rated speed.

The indicator cards of supercharged engines, which Mr. Prescott gives, are most surprising to a supercharger engineer. Supercharging at sea-level, or ground boost, has always been thought to make the pressure during the intake stroke greater than the pressure during the exhaust stroke, giving a so-called "positive loop" in the indicator card, which added to the area of the main indicator card and served to furnish most of the power required for driving the supercharger. Mr. Prescott's cards show that the supercharger cannot overcome restrictions so as to accomplish this. The intake pressure always is less than the exhaust pressure, hence the light-spring card gives a negative loop, to be subtracted from the main area. The supercharger helps to fill the cylinder, but only at a very late period, and principally serves to force the charge through restrictions. Now that a good indicator is available, no doubt engine details can be arranged so as to enable superchargers to supercharge.

Ford L. Prescott:—As Dr. Moss has pointed out, the use of indicators in steam-engine valve-setting has proved far superior to listening to the exhaust or observing the power. This is because no time is lost in "feeling around" for the best valve-setting. An experienced steam engineer, knowing what effect steam and exhaust lead have on the shape of the card, can with an indicator quickly arrive at the best valve-setting. On the other hand, an inexperienced engineer does not know how to recognize and correct faults in the indicator card. This is true to an even greater extent in internal-combustion-engine research, for here we are dealing with the working medium in two states: unburned and burned.

The critical point in the cycle is at top center, on the

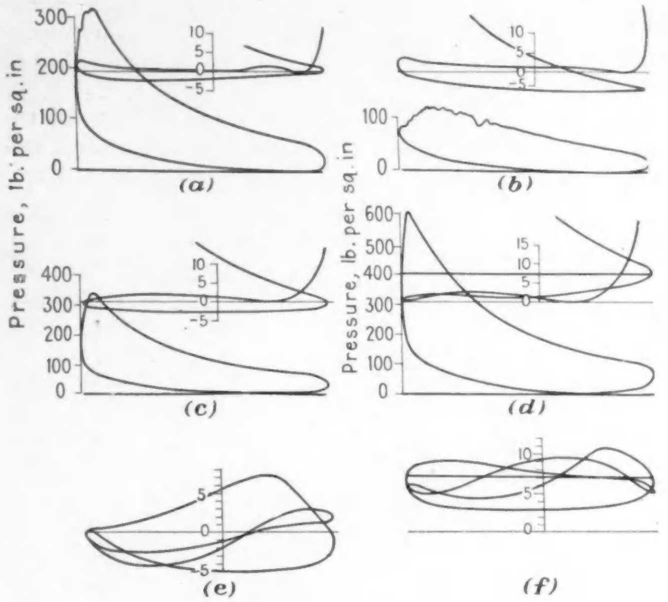


Fig. 5—Indicator Cards Obtained on an Air-Cooled Single-Cylinder Engine Showing Effects That Led to Changes Which Greatly Improved the Power Output.

Engine Bore, 5¾ In.; Stroke, 5½ In.; Compression Ratio, 5:1.

(*a*) Typical Card at 1300 R.P.M. with original Cams. B.M.E.P., 107 Lb. per Sq. In.

(*b*) Typical Card at 1900 R.P.M. with Original Cams. B.M.E.P., 49.5 Lb. per Sq. In.

(*c*) Typical Card at 2000 R.P.M. with New Cams. B.M.E.P., 110 Lb per Sq. In.

(*d*) Typical Card at 1800 R.P.M. with New Cams and 14 6-In. Supercharger Pressure. B.M.E.P., 210 Lb. per Sq. In.

(*e*) Intake-Pipe Card at 1800 R.P.M., Unsupercharged.

(*f*) Intake-Pipe Card at 1800 R.P.M., with 14.4-In. Supercharger Pressure.

exhaust stroke, where the cylinder volume is at the minimum and the exhaust valve is closing and the intake valve opening. No good is accomplished by re-compressing some of the products of combustion, as is common in steam-engine practice, because this space is much better filled with unburned charge. Hence not closing the exhaust valve too early is important. Again, no good is accomplished by late opening of the intake valve, since this reduces the already short time available for filling the combustion chamber. The use of overlap of exhaust and intake periods, mentioned by Dr. Moss, is essential to high cylinder output, since it permits the scavenging of the cylinder with the new charge. In cases where the fuel is injected into the cylinder, very great overlaps have been shown to be beneficial, but where the carbureted mixture is forced in by a supercharger, extreme overlap results in excessive loss of fuel, which is merely blown through the combustion space and out of the exhaust port. Thus, a balance must be struck between specific output and specific fuel consumption.

In one case the output of an engine was greatly improved by substituting new cams of the same maximum lift and approximately the same period of opening but having a greater mean lift. The improvement was due entirely to elimination of "wire-drawing" at the beginning and end of the intake and exhaust strokes. This was clearly indicated on the cards, which are reproduced in Fig. 5. Cards (*a*) and (*b*) show typical operation at 1300 and 1900 r.p.m. with the original cams. The effects of throttling are observed in the low pressure at which compression begins and in the low maximum pressure reached. The brake mean effective pressure was 49.5 lb. per sq. in. Exhaust throttling is also indicated in the residual pressure of 4 lb. per sq. in. at the end of the exhaust stroke. The throttling effects are greatly reduced at 1300 r.p.m., as shown in card (a), which shows 107 lb. per sq. in. b.m.e.p. While these cams are unsatisfactory for single-cylinder work, they give very good results in the nine-cylinder radial engine in which they are used.

In this engine, the length of intake pipe from carbureter inlet to intake valve is approximately 3½ ft. Treated as an opened organ pipe, since one or more intake valves are always open, the resonant frequency of the induction system in $n = v/WL = 1080/(2 \times 3.5) = 154.5$ per sec., where v = velocity and WL = wave length. The engine speed at which resonance would occur is $(154.5/4.5) \times 60 = 2060$ r.p.m. The rated speed is 1950 to 2200 r.p.m., depending upon the service required of the engine. To secure resonance on a single-cylinder engine would require an induction pipe $9 \times 3.5 = 31.5$ ft. long under the same conditions. Hence, cams that are suited to the nine-cylinder engine are poorly adapted to the single-cylinder engine, where intake-pipe resonance does not occur.

Card (*e*) in Fig. 5 shows the pressure cycle in the intake port when card (*c*) was taken. Card (*d*) shows the same conditions of valve timing as (*c*) but with 14.6-in. supercharge and 210 lb. per sq. in. b.m.e.p. Earlier opening of the intake valve would have resulted in a positive loop of power on the exhaust and intake strokes, but, since the purpose of the test had been attained, further change in valve timing was not made. Card (*f*) shows the intake-pressure cycle when card (*d*) was taken.

Cards (*e*) and (*f*) both show the effects of gas inertia or "ram" and explain why the compression line begins at a point above the actual manifold pressure. The drop in exhaust pressure to zero at the end of the exhaust stroke shows that inertia of the exhaust gases is also effective in scavenging the cylinder. Another test on a 12-cylinder engine proved that divided exhaust manifolds, which eliminate exhaust interference from one cylinder to another, actually scavenged the cylinders to a lower residual pressure than short individual exhaust pipes. This is important in connection with exhaust-driven superchargers and mufflers.

The author does not intend to claim that his instrument alone is capable of producing these results. He pointed out that the De Juhasz indicator gave equally good results on weak-spring cards, which, after all, are of much greater importance than the high-pressure cards in improving cylinder performance.

Mr. Prescott, in his paper, stated that the electric indicator is the most satisfactory device for transient and qualitative work such as combustion study, but the sampling type is better suited for engine development, valve-timing studies, supercharging and similar work.